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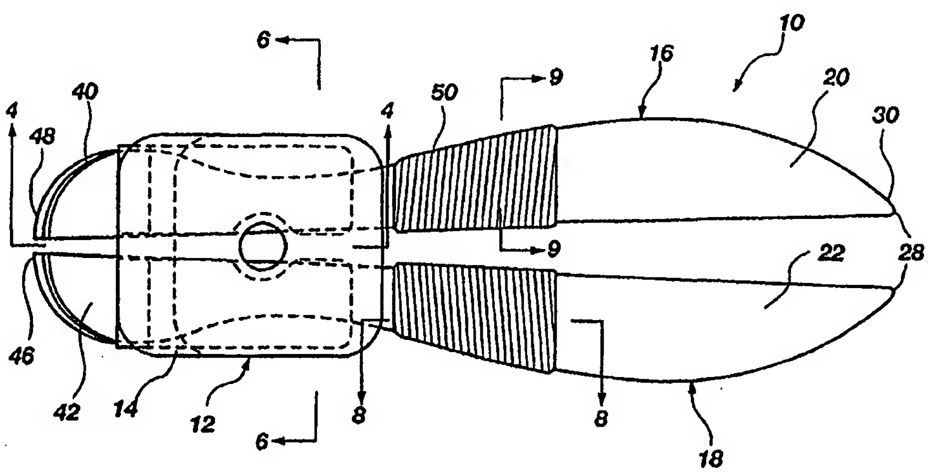

(57) Abstract

A prosthetic foot (10), having a forefoot member (20, 22) and a heel member (40, 42), may be comprised of two separate members forming opposite halves of the foot generally about the longitudinal axis of the foot for simulating natural rotation of the toes of a real foot. The forefoot member of the foot forms a resilient arc extending from a fixture member (12) or attachment location to a toe position and having an attachment portion (26), a curvilinear spring portion (32), an arch portion (34), and a toe portion (28). The heel member extends between the forefoot member, the heel position having an attachment portion (44), and a heel portion (46). The foot preferably has a mating member such as a rib, and groove type connection between the forefoot, the heel members for preventing the forefoot, the heel portions from sliding, and rotating with respect to each other.

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PROSTHETIC FOOT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a resilient prosthetic foot that has a reinforcement member to provide reinforcement, multiple forefoot members to simulate toe rotation, and/or a resilient ankle joint to resist lateral rotation of the foot relative to the ankle.

2. Prior Art

Many individuals have lost a limb for various reasons including war, accident, or disease. In most instances these individuals are not only able to live relatively normal lives, but physically active lives as well. Often times, these individuals are aided in their everyday lives by a prosthetic limb. The objective of prosthesis is to provide an artificial limb that simulates the function and natural feel of the replaced limb.

With respect to prosthetic feet, the development of a functional and natural artificial foot has been limited only by material and imagination. Many designs have attempted to copy the anatomy of the foot or simulate its actions by replacing the bones and muscle with various mechanical components. Other designs have departed radically from mere anatomical copying or mechanical simulation by replacing the entire foot with an energy storage element such as a spring. As the user steps onto the foot, the user's weight compresses the spring. As the user moves forward, the user's weight comes off the foot and the energy stored in the spring is used to propel the user

forward. Examples of such energy storing, spring-like feet having a forefoot member and a heel member include U.S. Patents 5,037,444 and 4,547,913 to Phillips.

The stiffness of prosthetic feet typically vary according to the intended use. Feet intended for everyday use typically require a soft feel and thus incorporate a loose spring. Feet intended for athletic use typically require strength and thus incorporate a stiff spring. Although different feet may be changed to suit the particular activity, such switching is inconvenient and at times it is impossible, such as a sudden need to run to catch, or avoid being hit by, a bus. Feet designed for particular purposes are typically unsuited for other purposes. Stiff, athletic feet are too hard for everyday use, and loose, everyday feet are too fragile for athletic use. Multiple-use feet have been designed which are capable of many different uses, but without being particularly well suited for any use.

In addition, the performance of these energy storing feet has been altered in various ways, such as by using multiple springs in various configurations, using bladders or resilient materials disposed between various elements, and using multiple springs that deflect at different intervals of foot deflection to add resistance. Examples of such feet include U.S. Patents 5,290,319 and 5,387,246 to Phillips; and 4,721,510 to Cooper et al. One problem with all these configurations is that the foot forms a unitary member incapable of providing independent and multiple

responses to uneven terrain, such as a slope. The unitary member is a platform that must rotate as a single body to conform to the slope of the terrain in an unnatural manner. Such a foot is incapable of rotating about a longitudinal axis.

Almost all of the past designs have focused on the major aspect of the prosthetic foot -- movement of the ankle or foot as it relates to walking or running. Few designs consider the workings of the toes or the less conspicuous movements of the foot and ankle, such as the rotation of the foot and toes when the user stands on an incline. In a natural foot, the foot and toes rotate to conform to the slope of the terrain. The artificial foot of previous designs usually incorporates a unitary foot and toe platform that is incapable of such independent rotational movement or response. Examples of such feet include U.S. Patents 5,037,444 and 4,547,913 to Phillips.

As an additional disadvantage, many feet have a forefoot portion and a heel portion attached by a bolt and nut through a bore. Such a bore in a structural member or spring member causes stress concentrations in the material which can lead to catastrophic failure. The heel portion acts as a lever. When in use, all the weight of the wearer is placed on the heel as the users steps forward. Therefore, a large stress is caused at the connection end of the heel portion which is concentrated at the bore and may break the heel portion. Furthermore, a shear stress is placed on the bolt because the forefoot and heel portions tend to slide with respect to each other.

The tendency to slide also concentrates the force applied by the user (static weight and dynamic walking) in the small area around the bore.

As an additional disadvantage, some feet have a forefoot portion and the heel portion bound together with a resin impregnated filament binding by winding the filament around the members. Problems with this type of joining technique are (i) the lack of strength in the connection to resist shear forces and (ii) the vulnerability of the connection to shear stress. The real strength of fibers is their tensile strength, or the strength of the fibers under loads along the length of the fibers. Thus, filaments circularly wound around two members would be most successful in resisting tensile forces *pulling* the two members apart. The filaments would be less successful in resisting shear forces *sliding or twisting* the two members apart. Because the foot is subject to so many different forces in many different directions, it is critical that structural or spring members be attached by a method capable of withstanding the numerous applied forces.

Many known devices also incorporate joints that allow plantar-dorsiflexion and lateral flexion of the foot relative to the leg. However, one common failure of many known prosthetic joints is that they do not allow for lateral rotation of the foot relative to the ankle. Of the known devices that do allow lateral rotation, many unnaturally constrain the rotation, such as in U.S. Patent No. 3,956,775 to Moore, or allow rotation only in discrete increments, such as

U.S. Patent No. 4,865,611 to Al-Turaiki, or allow it in an unnatural manner, such as in U.S. Patent Nos. 5,019,109 to Voisin and 5,030,239 to Copes. Such lateral rotation is desirable for athletic activities such as golf, basketball, and other sports where lateral rotation of the foot relative to the ankle is desirable. Moreover, resilient resistance to such rotation is desirable to approximate the function of the human ankle.

Therefore, it would be advantageous to develop a prosthetic foot capable of more naturally simulating a real foot, including toe rotation, and ankle/foot rotation. It would also be advantageous to develop a prosthetic foot having a reinforcement member. In addition, it would be advantageous to develop a prosthetic foot having various degrees of stiffness.

OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to provide a prosthetic foot capable of simulating a foot, including toe rotation and ankle/foot rotation.

It is another object of the present invention to provide a prosthetic foot capable of various different stiffness through a range of motion of the foot.

It is yet another object of the present invention to provide a prosthetic foot with a reinforcement member to reinforce the forefoot, heel, or both.

These and other objects and advantages of the present invention are realized in a prosthetic foot which may have multiple forefoot members to simulate toe rotation, a reinforcement member to provide reinforcement, and/or a resilient ankle joint to

resist lateral rotation of the foot relative to the ankle.

In accordance with one aspect of the present invention, the foot may have at least two forefoot members, at least one heel member, and at least one reinforcement member. First and a second forefoot members are coupled at an attachment location, near a socket for receiving a stump of an amputee, and extend to a toe location. The heel member is coupled near an arch portion of the forefoot member and extends to a heel location. Because the foot has a first and second forefoot member, the foot is able to respond to uneven terrain more like a natural foot having rotating toes. The heel member may also consist of a first and a second heel members.

The heel and forefoot members are resilient and deflect, or move, through a range of motion as a force is applied, such as the user's weight. A normal range of motion occurs during normal activity, such as walking. An extreme range of motion occurs during extreme activity, such as running. The heel and forefoot members also have a resistance response, such as a spring force or stiffness, to the applied force.

At least one resilient reinforcement member is coupled to the forefoot member and extends to a free section operable within the range of motion of any of the heel or forefoot members. A forefoot reinforcement member may be coupled near the attachment section and extend to a free section operable within the extreme range of motion of the forefoot members. A heel reinforcement member may be

coupled to the forefoot reinforcement member and extend to a free section operable within the extreme range of motion of the heal member.

As the foot is used under normal activity, the heel and forefoot members move through a normal range of motion. As the foot is used under extreme activity, the heel and forefoot members move into the extreme range of motion and the reinforcement members are engaged to reinforce the heel and forefoot members. Therefore, the foot has a soft feel during normal use, but is reinforced by the reinforcement member during extreme use.

The reinforcement member may take various configurations. It may be a single forefoot reinforcement member disposed between the forefoot members and extending between the attachment location and the free section. It may be a single heel reinforcement member coupled to the forefoot members at an arch portion or the attachment location or coupled to the reinforcement member. It may be both a forefoot and a heel reinforcement member.

In accordance with another aspect of the present invention, the foot may have a resilient forefoot member and a resilient forefoot reinforcement member. The forefoot member has a base end coupled proximal an attachment location, and extends forward to a toe end at a toe location. In addition, the forefoot member defines an arch section between the base end and the toe end. The forefoot member moves through a range of motion with multiple stages of advancement, including at least a normal range and an extreme range. The

resilient forefoot member has a resistance response to an applied force.

The forefoot reinforcement member has a base section coupled to the forefoot member at the arch section, and extends to a free end at a location between the arch section and the attachment location. The free end is spaced from the forefoot member and is disposed within the extreme range of motion of the forefoot member. The reinforcement member itself has a range of motion within the extreme range of motion of the forefoot member. Thus, the forefoot reinforcement member influences the range of motion and resistance response of the forefoot member.

A resilient heel member may have a base end coupled to the resilient forefoot member, and extend rearward to a heel end at a heel location. Like the forefoot member, the heel member has a range of motion including a normal range and an extreme range, and has a resistance response to an applied force.

A heel reinforcement member may have a base section coupled to the forefoot member at the arch section, and extend under the forefoot member to a free end proximal the attachment location. The free section is disposed within the extreme range of motion of the forefoot member. Like the forefoot reinforcement member, the heel reinforcement member has a range of motion within the extreme range of motion of the forefoot member, and thus, the heel reinforcement member influences the range of motion and resistance response of the forefoot member and the heel member.

A heel reinforcement member may form an arcuate section which extends near the heel location, and within the extreme range of motion of the heel member.

A secondary forefoot reinforcement member may have a base section coupled to the forefoot member at the arch section, and extending to a free end proximal the toe location. The free end is spaced above the toe end of the forefoot member, and is disposed within the extreme range of motion of the forefoot member, or toe end. The secondary forefoot reinforcement member has a range of motion within the extreme range of motion of the forefoot member, or toe end, and thus, influences the range of motion and resistance response of the forefoot member.

In accordance with another aspect of the present invention, the foot may have first and second foot members, or a split forefoot member. The foot, having a forefoot member and a heel member, may be comprised of two separate members forming opposite halves of the foot generally about the longitudinal axis of the foot. Because the foot has two halves, or a first and second member, the foot is able to respond to uneven terrain more like a natural foot having rotating toes.

In accordance with another aspect of the present invention, the foot may have mating means. The mating means may be a rib-and-groove type connection between the forefoot and heel members. The rib-and-groove connection prevents the forefoot and heel portions from sliding and rotating with respect to each other and thus prevents shear stress from being placed on the fibers holding the members together.

In accordance with another aspect of the present invention, the foot may have a rotatable bearing means disposed between and affixed to the end of an artificial limb, such as a leg, and the connection point of an artificial appendage such as a foot so as to allow rotation of the appendage about the long axis of the limb. A cylindrical sleeve of resilient polymer material, such as polyethylene, with or without fiber reinforcement, encases the rotatable bearing means with its long axis collinear to the axis of rotation of the bearing means, and the inside surface of the sleeve is affixed to the top and bottom portions of the rotatable bearing means, with the central portion of the cylinder of resilient material not affixed to the bearing means, such that when the appendage is transversely rotated relative to the limb, such rotation is resiliently resisted by torsional flexure of the central portion of the sleeve.

These and other objects, features, advantages and alternative aspects of the present invention will become apparent to those skilled in the art from a consideration of the following detailed description taken in combination with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top view of a prosthetic foot incorporating a preferred embodiment of the present invention.

FIG. 2 is a front elevational view of the prosthetic foot incorporating a preferred embodiment of the present invention.

FIG. 3 is a top cross section view of a preferred embodiment of the prosthetic foot of the present invention taken along line 3-3 of FIG. 2.

FIG. 4 is a elevational cross section view of a preferred embodiment of a fixture member of the prosthetic foot of the present invention taken along line 4-4 of FIG. 1.

FIG. 5 is a top cross section view of a preferred embodiment of the fixture member of the prosthetic foot of the present invention taken along line 5-5 of FIG. 2.

FIG. 6 is a front cross section view of a preferred embodiment of the fixture member of the prosthetic foot of the present invention taken along line 6-6 of FIG. 1.

FIG. 7 is a front cross section view of an alternative embodiment of the fixture member of the prosthetic foot of the present invention.

FIG. 8 is an elevational cross section view of a preferred embodiment of a rib-and-groove mating means of the prosthetic foot of the present invention taken along line 8-8 of FIG. 1.

FIG. 9 is an elevational cross section view of a preferred embodiment of the rib-and-groove mating means of the prosthetic foot of the present invention taken along line 9-9 of FIG. 1.

FIG. 10 is a top cross section view of an alternative embodiment of the prosthetic foot of the present invention.

FIG. 11 is a top view of a prosthetic foot incorporating a preferred embodiment of a reinforcement member of the present invention.

FIG. 12 is a side elevational view of the prosthetic foot incorporating a preferred embodiment of a reinforcement member of the present invention.

FIG. 13 is a top view of an alternative embodiment of a reinforcement member of the prosthetic foot of the present invention.

FIG. 14 is a side elevational view of an alternative embodiment of a reinforcement member of the prosthetic foot of the present invention.

FIG. 15 is a top view of an alternative embodiment of a reinforcement member of the prosthetic foot of the present invention.

FIG. 16 is a side elevational view of an alternative embodiment of a reinforcement member of a prosthetic foot of the present invention.

FIGs. 17-20 are side elevational views of an alternative embodiment of a reinforcement member of a prosthetic foot of the present invention.

FIGs. 21 and 22 are a top view of an alternative embodiment of a reinforcement member of the prosthetic foot of the present invention.

FIGs. 23 and 24 are a side elevational view of an alternative embodiment of a reinforcement member of a prosthetic foot of the present invention.

FIG. 25 is a side elevational view of an alternative embodiment of a reinforcement member of a prosthetic foot of the present invention.

FIG. 26 is a side elevational view of an alternative embodiment of a reinforcement member of a prosthetic foot of the present invention.

FIG. 27 is a side elevational view of an alternative embodiment of a reinforcement member of a prosthetic foot of the present invention.

FIG. 28 is a partial side view of the preferred embodiment of the prosthetic foot of the present invention.

FIG. 29 is a partial side view of an alternative embodiment of the prosthetic foot of the present invention.

FIG. 30 is a partial side view of an alternative embodiment of the prosthetic foot of the present invention.

FIG. 31 provides a cross-sectional view of the prosthetic joint of the present invention installed as it would be used to join a prosthetic foot to a prosthetic leg.

FIG. 32 provides a close-up cross-sectional view of the prosthetic joint of FIG. 31.

FIG. 33 shows a pictorial view of the prosthetic joint of the present invention connected to an energy-storing foot structure in its natural, un-deflected configuration.

FIG. 34 shows a pictorial view of the prosthetic joint of the present invention connected to a laterally deflected energy-storing foot structure.

FIG. 35 shows a pictorial view of the prosthetic joint of the present invention in which the resilient sleeve includes full-depth vertical slots.

FIG. 36 shows a pictorial view of the prosthetic joint of the present invention in which the resilient sleeve includes full or partial depth slits in its side.

FIG. 37 depicts an alternative embodiment of the resilient sleeve of FIG. 35 wherein the slots are slanted.

FIG. 38 depicts an alternative embodiment of the resilient sleeve of FIG. 35 wherein the slots are curved.

FIG. 39 depicts an alternative embodiment of the resilient sleeve of FIG. 36 wherein the slits are slanted.

FIG. 40 depicts an alternative embodiment of the resilient sleeve of FIG. 36 wherein the slits are curved.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made to the drawings in which the various elements of the present invention will be given numerical designations and in which the invention will be discussed so as to enable one skilled in the art to make and use the invention.

Toe Rotation

As illustrated in FIGs. 1 and 2, a preferred embodiment of a prosthetic foot, indicated generally at 10, of the present invention is shown. The prosthetic foot 10 has a fixture member 12 for attachment to a socket (not shown) for receiving a stump of an amputee. The socket is configured for the specific needs of the amputee but typically has a portion adapted for attachment to a standard fixture,

such as fixture member 12. The fixture member 12 has a generally horizontal surface 14 for contacting the socket. The standard fixtures typically have a generally horizontal surface, as shown in FIGs. 1 and 2, or a generally vertical surface (not shown).

In the preferred embodiment, the prosthetic foot 10 has a first member 16 coupled to the fixture member 12 and a second member 18 coupled to the fixture member 12, as shown in FIG. 1. Referring to FIG. 2, the first member 16 and second member 18 have forefoot members 20 and 22, and heel members 40 and 42. The second member 18 is disposed adjacent the first member 16, and is independently movable with respect to the first member 16.

The prosthetic foot 10, or first and second members 16 and 18, advantageously has at least two resilient forefoot members. In the preferred embodiment, the foot 10 has a first forefoot member 20 and a second forefoot member 22. The forefoot members 20 and 22 have base ends 24 coupled near an attachment location 26. The attachment location 26 is near a stump of an amputee and the base ends 24 of the forefoot members 20 and 22 attach to the fixture member 12 or a socket (not shown) for receiving the stump of the amputee.

The forefoot members 20 and 22 extend forward from the base ends 24 to toe ends 28 at a general toe location 30. The toe location 30 is a region near the forward end of the foot where toes of a natural foot would be located.

The forefoot members 20 and 22 form a vertically oriented arc extending between the base ends 24 at the attachment location 26 and the toe ends 28 at the toe location 30. The forefoot members 20 and 22 have curvilinear spring portions 32 extending from the base ends 24 and arch portions 34 extending from the spring portions 32 to the toe ends 28.

The forefoot members 20 and 22 are preferably made of a resilient material. As the user steps, or pivots forward, on the prosthetic foot 10, the forefoot members 20 and 22 deflect. Because the forefoot members 20 and 22 are made of a resilient material, the forefoot members act as springs and store the energy to be released as the user moves forward.

The forefoot members 20 and 22 have a range of motion with multiple stages of advancement. The members engage a surface, such as the ground, either directly or through a shoe. As the user steps, or pivots forward, on the prosthetic foot 10, an applied force, such as the users weight, causes the members to deflect through the range of motion. The range of motion includes at least a normal range and an extreme range. The forefoot members 20 and 22 move through the normal range during normal activity, and through the normal range and into the extreme range during extreme activity. The normal activity includes activities such as walking and standing. The extreme activity includes activities which deflect the forefoot members beyond the normal range and deflection, such as when running and jumping.

The forefoot members 20 and 22 also have a resistance response to an applied force. The resistance response is the stiffness or spring force exerted by the members in response to the applied force. The applied force includes the static weight of the user and dynamic impact forces exerted on the foot during use.

The prosthetic foot 10 may have at least one resilient heel member. The foot 10 may have a first heel member 40 and a second heel member 42. The heel members 40 and 42 have base ends 44 coupled to the forefoot members 20 and 22. The base ends 44 preferably couple to the forefoot members 20 and 22 at the arch portions 34. The heel members 40 and 42 extend rearward from the base ends 44 to heel ends 46 at a general heel location 48. The heel location 48 is a region near the rearward end of the foot where the heel of a natural foot would be located. The heel members 40 and 42 preferably form an arc extending between the base ends 44 and the heel ends 46 at the heel location 48.

It is of course understood that the heel members may be coupled to the forefoot members at any appropriate location, including the attachment location. In addition, the heel members may comprise a single heel member.

The heel members 40 and 42 may be attached to the forefoot members 20 and 22 by wrapping the base ends 44 of the heel members and the arch portion 34 of the forefoot members with a resin impregnated fiber 50. Alternatively, any appropriate means may be used

including bolting or even forming the heel members integrally with the forefoot members.

The heel members 40 and 42 are also made of a resilient material. As the user steps on the prosthetic foot 10, the heel members 40 and 42 deflect. Because the heel members 40 and 42 are made of a resilient material, they act as springs and cushion the force of the foot 10 as it contacts the ground and store energy.

The heel members 40 and 42 also have a range of motion with multiple stages of advancement. The members engage a surface, such as the ground, either directly or through a shoe. As the user steps on the prosthetic foot 10, an applied force, such as the users weight, causes the members to deflect through the range of motion. The range of motion includes at least a normal range and an extreme range. The heel members 40 and 42 move through the normal range during normal activity, and through the normal range and into the extreme range during extreme activity. The heel members 40 and 42 also have a resistance response to an applied force.

The first and second forefoot members 20 and 22, as well as the first and second heel members 40 and 42, are disposed adjacent one another with a space or gap separating them. The forefoot members 20 and 22, and the heel members 40 and 42, are independently movable with respect to each other. The forefoot members, and the heel members, may be mirror images of one another. Alternatively, the first and second

forefoot members 20 and 22 may be configured to resemble an actual foot.

Because the foot 10 is advantageously composed of two members 16 and 18, or two forefoot members 20 and 22 and two heel members 40 and 42, the foot 10 is able to respond to uneven terrain more like a natural foot with rotating toes. In addition, the foot 10 is better able to simulate toe and axial foot rotation. Furthermore, first and second members of either the forefoot and/or heel may have different spring forces, or stiffness, to better simulate a natural foot. Therefore, the multiple member forefoot of the present invention presents a significant improvement over prior art feet by providing multiple members to respond as multiple toes of a real foot would respond and by providing forefoot members of varying stiffness to simulate the varying strengths of individual toes of a real foot.

Referring to FIG. 4, the fixture member 12 has an upper plate 60 and a lower plate 62. The attachment portion 30 of the first and second members 16 and 18, or attachment ends 26 of the forefoot members 20 and 22, are coupled to the fixture member 12 between the upper and lower plates 60 and 62. A bore 64 passed through the upper and lower plates 60 and 62 so that the fixture member 12 may be attached to a socket (not shown) by a bolt or screw or the like. Referring to FIG. 5, the lower plate 62 has recesses 66 formed therein for receiving the attachment portion 30 of the first and second members 16 and 18. The recesses 66 are formed to hold the attachment portion 30 firmly.

Referring to FIG. 6, the first and second members 16 and 18 are held in the recesses 66 such that the members 16 and 18 are substantially parallel with the ground. Referring to FIG. 7, an alternative embodiment of the fixture member 12 is shown. The fixture member 12 may incorporate an angle adjustment means for adjusting the angle of the forefoot member and/or heel member with respect to the ground. As shown in FIG. 7, the recesses 66 formed in the lower plate 62 may have an angle so that the first and second members 16 and 18 are at an angle with respect to the fixture member 12 and the ground.

As illustrated in FIGs. 8 and 9, the forefoot members 20 and 22 and the heel members 40 and 42 have a mating means. The forefoot members 20 and 22 and heel members 40 and 42 are preferably attached by a resin impregnated fiber 50. The tensile strength of this attachment, or the strength of the fibers along its length, is very strong. So the attachment is able to resist forces tending to pull the members apart. Fibers, however, lack strength in resisting shear forces. Thus the filaments would be less successful in resisting shear forces tending to slide the two members apart. Because a prosthetic foot is subject to many different forces in many different directions, it is critical that the members be attached by a method capable of withstanding the numerous applied forces.

Preferably, the mating means is a rib-and-groove type attachment between the forefoot members 20 and 22 and the heel members 40 and 42. Referring to FIG. 8,

a lateral rib 80 formed in the forefoot member 24 mates with a lateral groove 82 formed in the heel member 26. It is of course understood that a rib 84 may be formed in the heel members 40 and 42 to mate with a groove 86 formed in the forefoot members 20 and 22 or that there may be multiple ribs and grooves formed in either member. The ribs 80 and 84 and the grooves 82 and 86 are formed laterally with respect to the foot 10. This prevents twisting and longitudinal sliding between the forefoot members 20 and 22 and the heel member 40 and 42.

Referring to FIG. 9, a longitudinal rib 88 formed in the forefoot member 24 mates with a longitudinal groove 90 formed in the heel members 40 and 42. It is of course understood that a rib 92 may be formed in the heel members 40 and 42 to mate with a groove 94 formed in the forefoot members 20 and 22 or that there may be multiple ribs and grooves formed in either member. The ribs 88 and 92 and the grooves 90 and 94 are formed longitudinally with respect to the foot 10. This prevents twisting and lateral sliding between the forefoot members 20 and 22 and the heel members 40 and 42.

As illustrated in FIG. 10, an alternative embodiment of a prosthetic foot 100 of the present invention is shown. The foot 100 has a forefoot member 102 and a heel member 104. The forefoot member 102 forms an arc extending between the fixture member (not shown) and a toe position 106. Like the above embodiment, the forefoot member 102 has an attachment

portion, a curvilinear spring portion, an arch portion and a toe portion.

The heel member 104 extends between the forefoot member 102 and a heel position 108. Like the preferred embodiment, the heel member 108 has an attachment portion and a heel portion.

The heel member 104 is preferable attached to the forefoot member 102 at an intersection between the toe portion and the arch portion. In addition, the heel member 104 is preferably attached to the forefoot member 102 by wrapping the attachment portion of the heel member 102 and the intersection with a resin impregnated fibre 110.

A slit 112 is formed in the forefoot member 102 extending from an open end at the toe position 106 to at least the heel portion 104. Because the forefoot member 102 has a slit 112, the toe portion of the forefoot member 102 is divided into a first protrusion 114 and a second protrusion 116. The two protrusions 114 and 116 allow the foot 100 the ability to respond to uneven terrain more like a natural foot with rotating toes.

Reinforcement

As illustrated in FIGs. 11 and 12, an alternative embodiment of a prosthetic foot 210 of the present invention is shown, and advantageously has at least one resilient reinforcement member. The reinforcement member has a base section coupled to the forefoot members and extends to a free section. The free section operates within the extreme range of motion of any of the forefoot members or heel members and is

freely moveable with respect to the members. The reinforcement member influences the range of motion and resistance response of any of the forefoot members or heel members.

The foot 210 may have at least one forefoot reinforcement member 260. The forefoot reinforcement member 260 has a base section 262 coupled to at least one of the forefoot members 20 and 22. The base section 262 is preferably coupled with both forefoot members 20 and 22 near the attachment location 26. The forefoot reinforcement member 260 extends forward to a free section 264. The free section 264 of the reinforcement member 260 is not rigidly attached to the foot 210, but is freely moveable with respect to the foot. The free section 264 may be non-rigidly coupled to the forefoot or heel members as discussed below. The free section 264 operates within the extreme range of motion of the forefoot members.

In addition, the foot 210 may have at least one heel reinforcement member 266. The heel reinforcement member 266 has a base section 268 coupled to the forefoot reinforcement member 260. The heel reinforcement member 266 extends rearward to a free section 270. The free section 270 operates within the extreme range of motion of the heel members 40 and 42.

In normal use, the heel members 40 and 42 deflect, or move, through the normal range of motion as the user steps onto the foot 210. The heel members 40 and 42 engage the surface and the applied force of the user's weight causes the members to deflect. The forefoot members 20 and 22 also deflect, or move,

through the normal range of motion as the user pivots forward on the foot 210. The forefoot members 20 and 22 engage the surface and the applied force of the user's weight causes the members to deflect. The normal range of motion is a result of normal activities, such as walking, that exert a normal applied force on the foot.

During extreme activities, such as running, a more extreme applied force is exerted on the foot resulting in an extreme range of motion. The greater the force exerted on the foot, the greater the deflection, or movement in the range of motion. In extreme use, the heel members 40 and 42 move through the normal range of motion and into the extreme range of motion. As the heel members move into the extreme range of motion, the free section 270 of the heel reinforcement member engages the surface and deflects with the heel members. Likewise, as the forefoot members move into the extreme range of motion, the free section 64 of the forefoot reinforcement member engages the surface and deflects with the forefoot members. During extreme activities, the reinforcement members are advantageously engaged to add stiffness and strength to the foot. Because of the reinforcement members, softer or less resistant heel and forefoot members may be used for a softer, more cushioned feel without the fear of failure or need to change prosthetics should the need for greater activity arise.

The present invention provides a significant improvement over prior art prosthetic feet by

providing a multipurpose foot, having a reinforcement member to add stiffness during extreme activities while maintaining the softer heel and forefoot members during normal activities, and by providing a foot that simulates toe rotation, having at least a first and second forefoot members capable of independent movement.

Cushions 272 may be disposed on the heel, forefoot, and reinforcement members to soften or cushion the contact between the members and the surface. These cushions may be attached to the forefoot for providing initial contact, or may be positioned for engagement upon deflection to some predetermined degree.

As illustrated in FIG. 13, the prosthetic foot 278 may also have protrusions 280 formed on any of the forefoot or heel reinforcement members 282 or 284, or protrusions 286 formed on any of the forefoot or heel members 288 or 290, so that the reinforcement members are engaged by the heel and forefoot members as they move into the extreme range of motion, as opposed to being engaged by the surface. The protrusions 280 may be formed on the reinforcement members 282 and 284 and extend out over the forefoot and heel members 20 and 40. Alternatively, the protrusions 286 may be formed on the forefoot and heel members 288 and 290 and extend under the reinforcement members. The protrusions may be any suitable means of having the heel and forefoot members engage the reinforcement members, such as tabs, plates or rods.

As illustrated in FIG. 14, the prosthetic foot 292 may also have a strap 294 coupled between the reinforcement members and any of the heel and forefoot members. The strap limits the heel or forefoot member from abruptly returning to an unstressed position when the applied force is removed. In other words, the strap helps prevent the heel and forefoot members from snapping back. The straps also transfers some of the heel load to the toe member under heel loading and some of the toe load to the heel members during toe loading. The strap may be any suitable means for coupling the reinforcement member to the heel or forefoot member, such as a nylon cord or wire cable. It may also comprise a resilient polymer.

The configuration of the reinforcement member with respect to the heel and forefoot members may take various forms, examples of which are illustrated and described in the alternative embodiments. As illustrated in FIGs. 15 and 16, the at least one reinforcement member may be a single, forefoot reinforcement member 300 disposed between the first and second forefoot members 302 and 304 similar to the preferred embodiment. As also illustrated in FIG. 15, the at least one heel member may be a single heel member 306.

As illustrated in FIGs. 17 and 18, the at least one reinforcement member may be a single, heel reinforcement member 310 or 312. The heel reinforcement member 310 may have the base section 314 coupled to the forefoot members 20 and 22 at the arch location 34 and between the forefoot members and the

at least one heel member, as shown in FIG. 17. Alternatively, the heel reinforcement member 312 may have the base section 316 coupled to the forefoot members 20 and 22 at the attachment location 26.

As illustrated in FIGs. 19 and 20, the at least one reinforcement member may be a forefoot reinforcement member 60 and a heel reinforcement member 312 or 310.

As illustrated in FIG. 21, the reinforcement members 320 and 322 may be disposed so that a portion of the reinforcement member is directly above the heel or forefoot member. In this way, the reinforcement member is engaged directly by the heel or forefoot member as they move into the extreme range of motion without the need for a protrusion.

As illustrated in FIG. 22, the at least one reinforcement member may be a first forefoot reinforcement member 330, a second forefoot reinforcement member 332, a first heel reinforcement member 334, and a second heel reinforcement member 336. The first and second forefoot reinforcement members 330 and 332 may be disposed over the first and second forefoot member 20 and 22 respectively. Likewise, the first and second heel reinforcement members 334 and 336 may be disposed over the first and second heel members 40 and 42 respectively. In this way, the strengths or stiffness of the different reinforcement members, as well as the heel and forefoot members, may be varied to obtain the desired response and characteristic of the foot 10.

As illustrated in FIG. 23, the at least one reinforcement member may be a first heel reinforcement member 340 and a second heel reinforcement member 342. The first heel reinforcement member 340 has a base section 344 coupled to the forefoot reinforcement members 20 and 22 near the arch section 34 and extends to a free section 346 operable within the extreme range of motion of the heel member. The first heel reinforcement member 340 forms an arcuate section 348. The second heel reinforcement member 342 has a base section 350 coupled to the first and second forefoot members 20 and 22 near the attachment section 26 and extends to a free section 352 near the arcuate section 348 of the first reinforcement member 340. In this way, the first heel reinforcement section 340 reinforces the heel member as the heel member enters into a first stage of extreme range of motion while the second heel reinforcement member 342 reinforces the first heel reinforcement member 340 at a second, more extreme range of motion. The second heel reinforcement member also helps reinforce the forefoot members as the free section 352 abuts the arcuate section 348 of the first heel reinforcement member 340.

As illustrated in FIG. 24, the prosthetic foot may have multiple forefoot reinforcement members 60 and 360 and multiple heel reinforcement members 66 and 362. The reinforcement members may be disposed so that they engage at various intervals or stages of advancement throughout the full range of motion. The initial forefoot and heel reinforcement members 60 and

66 may act as primary reinforcement members and be engaged at a first stage of extreme range of motion, while the additional forefoot and heel reinforcement members 360 and 362 act as secondary reinforcement members and are engaged at a second stage of extreme range of motion.

As illustrated in FIG. 25, an alternative embodiment of a prosthetic foot 410 of the present invention is shown. The prosthetic foot 410 has a resilient forefoot member 420. The forefoot member 420 has a base end 424 coupled near an attachment location 26. The forefoot member 420 extends forward from the base end 424 to a toe end 428 at a general toe location 30. In addition, the forefoot member 420 forms a vertically oriented arc extending between the base end 424 at the attachment location 26, and the toe end 428 at the toe location 30. The forefoot member 420 has a curvilinear spring portion 432 extending from the base end 424, and an arch portion 434 extending from the spring portions 432 to the toe end 428. As described above, the forefoot member 420 is preferably made of a resilient material, has a range of motion with multiple stages of advancement, and also has a resistance response to an applied force.

The prosthetic foot 410 preferably has a resilient heel member 440. The heel member 440 has a base end 444 coupled to the forefoot member 420. The base end 444 of the heel member 440 preferably is coupled to the forefoot member 420 at the arch portion 434. The heel member 440 extends rearward from the

base end 444 to a heel end 446 at a general heel location 48. The heel member 440 preferably forms an arc extending between the base end 444 and the heel end 446 at the heel location 48. It is of course understood that the heel member may be coupled to the forefoot member at any appropriate location, including the attachment location. The heel member 440 may be attached to the forefoot member 420 as described above. In addition, the heel member 440 is made of a resilient material, has a range of motion with multiple stages of advancement, and also has a resistance response to an applied force.

The prosthetic foot 410 advantageously has at least one resilient reinforcement member, such as a forefoot reinforcement member, or heel reinforcement member. The reinforcement member has a base section coupled to the forefoot member and extends to a free section. The free section operates within the extreme range of motion of the forefoot member, and/or the heel member, and may be freely moveable with respect to the members. The reinforcement member influences the range of motion and resistance response of the forefoot member and/or heel member.

The foot 410 has a forefoot reinforcement member 460. The forefoot reinforcement member 460 has a base section 462 coupled to the upper or top side of the forefoot member 420. The base section 462 is preferably coupled to the arch portion 434 of the forefoot member 420. The forefoot reinforcement member 460 extends above the forefoot member 420 to a free section 464 at a location between the arch

section 434 and the attachment location 26, and preferably proximal to the attachment location 26. The free section 464 of the forefoot reinforcement member 460 is not rigidly attached to the forefoot member 420, but is moveable with respect to the forefoot member 420. The free section 464 may be non-rigidly coupled to the forefoot member 420 as discussed below. The free section 464 operates within the extreme range of motion of the forefoot member 420.

The prosthetic foot 410 may also have a flexible restraint 470, such as a strap, coupled to and between the free end 464 of the forefoot reinforcement member 460 and the forefoot member 420. The restraint 470 is flexible in the direction of the forefoot member 420 and forefoot reinforcement member 460 towards one another, but substantially non-flexible in the direction of the forefoot member 420 and forefoot reinforcement member 460 away from one another. Thus, restraint 470 allows the forefoot member 420 to move or deflect towards the reinforcement member 460, but couples the reinforcement member 460 to the forefoot member 420 as the forefoot member 420 moves or deflects away from the reinforcement member 460. Therefore, the restraint 470 transfers some of the heel load to the forefoot reinforcement member 460, as discussed more fully below. The restraint 470 may also have some play or slop of predetermined length to allow the reinforcement member 460 to move or deflect away from the reinforcement member 460 a predetermined distance before operatively coupling them together.

The restraint 470 may be a strap or any other suitable means for coupling the reinforcement member 460 to the forefoot member 420, such as a nylon cord or wire cable. It may also comprise a resilient polymer.

In normal use, the heel member 440 deflects, or moves, through the normal range of motion as the user steps onto the foot 410. The heel member 440 engages the surface and the applied force of the user's weight causes the heel member 440 to deflect through a range of motion. As the heel member 440 and the forefoot member 420 deflect or bend towards one another under the user's weight, the attachment of the heel member 440 to the forefoot member 420 tends to deflect or flex the forefoot member 420. The restraint 470, however, couples the forefoot reinforcement member 460 to the forefoot member 420 to reinforce the forefoot member 420 and adds additional resistance to movement or deflection of the forefoot member 420. In addition, coupling the reinforcement member 460 to the forefoot member 420 resists flexion or bending of the forefoot member 420, and the arch portion 434.

The forefoot member 420 also deflects, or moves, through the normal range of motion as the user pivots forward on the foot 410. The forefoot member 420 engages the surface and the applied force of the user's weight causes the members to deflect through a range of motion. The normal range of motion is a result of normal activities, such as walking, that exert a normal applied force on the foot.

During extreme activities, such as running, a more extreme applied force is exerted on the foot

resulting in an extreme range of motion. The greater the force exerted on the foot, the greater the deflection, or movement in the range of motion. In extreme use, the forefoot member 420 engages the free section 464 of the forefoot reinforcement member 460 and they deflect together. During extreme activities, the reinforcement member is advantageously engaged to add stiffness and strength to the foot 410, or the forefoot member 420. Because of the reinforcement member 460, softer or less resistant heel and forefoot members may be used for a softer, more cushioned feel without the fear of failure or need to change prosthetics should the need for greater activity arise.

The present invention provides a significant improvement over prior art prosthetic feet by providing a multipurpose foot, having a reinforcement member to add stiffness during extreme activities while maintaining the softer heel and forefoot members during normal activities.

The prosthetic foot 410 of the present invention preferably and advantageously has a secondary forefoot reinforcement member 480. The secondary forefoot reinforcement member 480 has a base section 482 fixedly coupled to the upper or top side of the forefoot member 420 at the arch portion 434. The secondary forefoot reinforcement member 480 extends above the forefoot member 420 to a free section 484 proximal the toe location 30 and spaced above the toe end 428. The free section 484 of the secondary forefoot reinforcement member 480 is not rigidly

attached to the forefoot member 420. The free section 484 operates within the extreme range of motion of the forefoot member 420, or the toe end 428, and has a range of motion within the extreme range of motion of the forefoot member 420, or toe end 428.

The toe end 428 of the forefoot member 420 deflects, or moves, through the normal range of motion as the user pivots forward on the foot 410. In extreme use, the toe end 428 of the forefoot member 420 engages the free section 484 of the secondary forefoot reinforcement member 480 and they deflect together. During extreme activities, the secondary reinforcement member is advantageously engaged to add stiffness and strength to the foot 410, or the toe end 428 of the forefoot member 420, and the arch portion 434.

The primary and secondary forefoot reinforcement members 460 and 480 may be integrally formed, as shown, with the base end 482 of the secondary member 480 being integrally formed with the base end 462 of the primary member 460. Thus, both members 460 and 480 extend from the arch portion 434 in opposite directions. Alternatively, the members 460 and 480 may be separate members.

The configuration of the reinforcement member with respect to the heel and forefoot members may take various forms, examples of which are illustrated and described in the alternative embodiments. Referring to FIG. 26, an alternative embodiment of the prosthetic foot 488 may have a heel reinforcement member 490. The heel reinforcement member 490 has a

base section 492 coupled to the lower side or bottom of the forefoot member 420, preferably at the arch portion 434. The heel reinforcement member 490 extends rearward to a free section 494 at a location between the arch portion 434 and the attachment section 26, and preferably proximal to the attachment location 26. The free section 494 is disposed within the extreme range of motion of the forefoot member 420, and may be freely moveable with respect to the forefoot member 420. The heel reinforcement member 490 has a range of motion within the extreme range of motion of the forefoot member 420.

As described above, a flexible restraint 496, such as a strap, may be coupled to and between the free end 494 of the heel reinforcement member 490 and the forefoot member 420. Again, the restraint 496 is flexible in the direction of the forefoot member 420 and heel reinforcement member 490 towards one another, but substantially non-flexible in the direction of the members 420 and 490 away from one another. Thus, the heel reinforcement member 490 allows the forefoot member 420 to move towards the heel reinforcement member 490, but couples the forefoot member 420 to the heel reinforcement member 90 in movement away from the heel reinforcement member 490. Therefore, the restraint 496 transfers some of the load to the heel reinforcement member 490. In addition, the restraint 496 may have a predetermined play or slop to allow movement away from each other. Together, the forefoot and heel reinforcement members 460 and 490 reinforce the forefoot member 420 in the extreme range of

movement, but in opposite directions of movement while the forefoot member 420 is in the normal range of movement.

Referring to FIG. 27, an alternative embodiment of the prosthetic foot 500 of the present invention may have only a heel reinforcement member 520. The heel reinforcement member 520 has a base section 522 coupled to the bottom of the forefoot member 420 near the arch location 434. The heel reinforcement member 520 extends to a free section 524 above the arch 434 and preferably near the attachment location 26. The reinforcement member 520 forms an arcuate section 526 that extends near the heel location 448. In this configuration, the reinforcement member 520 reinforces both the heel member 440 and forefoot member 420. The arcuate section 526 is engaged as the heel member moves into the extreme range of motion. A strap 528 couples the free section of the reinforcement member 520 to the forefoot member 420. As the forefoot member 420 moves into the extreme range of motion, the reinforcement member 520 reinforces the forefoot member 420.

Referring again to FIG. 25, cushions 530 may be disposed on the bottoms of the heel and forefoot members 440 and 420 to soften or cushion the contact between the members and the surface.

Referring to FIG. 28, a flexible cushion 540 may be disposed between the free end 464 of the forefoot reinforcement member 460 and the forefoot member 420 to cushion the contact between the two members 420 and 460. The cushion 540 may be a foam rubber material or

the like adhered to one or both surfaces of the members 420 and 460. As shown, the cushion 540 may substantially fill the space or distance between the two members 420 and 460. Alternatively, referring to FIG. 29, the cushion may be comprised of one or more cushions, such as a first cushion 542 attached to the reinforcement member 460, and/or a second cushion 544 attached to the forefoot member 420. The cushions 540, 542 and 544 not only cushion the contact between the two members 420 and 460, but gradually transfer force between the two members 420 and 460, or gradually change the resistance as the forefoot member 420 moves into the extreme range of movement and contacts the reinforcement member 460. Thus, the response of the foot 410 is a soft resistance by the forefoot member 420 and then an abrupt, stiff or hard resistance from both the forefoot and reinforcement members 420 and 460, but a soft response by the forefoot member 420 gradually transitioning through an increasingly hard and stiff resistance as the cushion 540, 542 and/or 544 is increasingly compressed.

Referring to FIG. 30, an air bag or bladder 550 containing air may be disposed between the forefoot member 420 and reinforcement member 460. A valve 554, such as a pin or needle valve, may be coupled to an opening 556 in the bag for releasing, and thus adjusting, the pressure of air in the bag 550. By adjusting the air pressure in the bag 550, the stiffness of the bag 550 is adjusted, and the performance characteristics of the foot 410 are varied. A small air pump 560 may be coupled to an

opening 562 in the bag 550 by a tube 564. The pump 560 may be a resilient bladder such that the bladder may be compressed, forcing out air, and released, drawing in air as the resilient bladder returns to its initial shape. The bladder has an air inlet 566 and an air outlet 568, and check valves 570 and 572 coupled to the inlet and outlet 568, respectively, such that air is permitted through the check valve 570 at the inlet 566 and into the bladder as the bladder expands, and out the check valve 572 at the outlet 568 as the bladder is compressed. The pump 560 may be secured to either member 420 or 460 in a convenient location, or may be releaseably secured to the air bag 550.

It is of course understood that the above discussion with respect to the cushion 540 and air bag 550 being disposed between the forefoot member 420 and forefoot reinforcement member 460 is equally applicable to a cushion or air bag being disposed between the forefoot member 420 and the heel reinforcement member 490.

Referring again to FIG. 25, flexible and resilient wedge members may be disposed between the various members to strengthen and/or stiffen the foot. The wedge members may have various different stiffness. For example, a wedge member 580 may be positioned between the forefoot member 420 and the forefoot reinforcement member 460 at a location proximal to the attachment. Another wedge member 582 may be positioned between the forefoot member 420 and the secondary forefoot reinforcement member 480. In

addition, a wedge member 584 may be positioned between the forefoot and heel members 420 and 440 proximal to the attachment.

Ankle/Foot Rotation

FIG. 31 provides a cross-sectional view of the prosthetic joint of the present invention as it would be used to join a prosthetic foot to a prosthetic leg, and FIG. 32 provides a close-up view of this joint. The joint, shown generally at 610, is installed as it would be used to join a prosthetic foot 612, having a resilient, energy-storing keel 616, to a prosthetic leg 614. The leg and foot may be of any construction known in the art, such as rigid foam or other durable, lightweight materials, and may comprise a flexible polyurethane skin or other aesthetically desirable configuration. The energy-storing keel 616 is well known in the art, and such devices are now commonly used for running and other athletic activities. It will be appreciated that the joint 610 as disclosed herein may be used to join parts of prosthetic limbs of other configurations such as prosthetic hands to arms, etc.

The joint 610 is generally comprised of an upper housing 618 and a central core 620. The upper housing and core are connected by bearing means 622, such as needle bearings, and resilient pads 624 which allow the housing and core to be freely rotatable with respect to each other about a vertical axis of rotation 626. It will be appreciated that the core 620, housing 618, bearings 622 and pads 624 will preferably be cylindrical in shape and coaxially

joined so as to allow axial rotation. As depicted in FIG. 32, there is also an annular ring 628 which joins the outside of the lower portion of the core 620, and supports the pads 624 and bearings 622. It will be appreciated that this ring could be integrally formed as part of the core 620 if it is so desired.

The joint 610 is connected to the foot 612 via a bolt 630 which engages the keel 616 with bolt head 632 and extends into the center of the core 620. As shown in FIG. 31 and FIG. 32, the bolt 630 threadably engages the core 620 so as to securely attach the joint 610 to the foot 612. It will be appreciated that other means may be employed to securely attach the joint to the foot yet prevent rotation of the core 620 and ring 628 relative to the foot 612. As depicted in FIG. 31, the foot 612 is advantageously provided with a cylindrical opening 631 which surrounds the bolt head 632 and extends from the bolt head to the bottom of the foot. This opening allows easy access to the bolt head by, for example, a socket wrench for quickly and easily disconnecting the foot 612 from the ankle 614 when needed for maintenance or to change the sleeve 638, as will be discussed below. The bottom of the opening 631 may be plugged with a plug 633 as shown for aesthetic purposes and to provide a desirably large bearing surface on the bottom of the foot 612.

The foot structure includes a flat top plate 636 to facilitate secure attachment of the core 620 and ring 628 to the top of the foot keel, which has a partly curved upper surface. At the upper end, the

housing 18 is attached to the leg 614 by means of an attachment part 634, such as an inverted pyramid or knob, atop the center of the housing. This knob is axially aligned with the bolt 630, and engages the material of the leg in such a way as to prevent rotation of the housing relative to the leg.

With the joint as heretofore described, the foot may freely rotate about axis 626 in a full circle. However, to provide resilient resistance to this rotation, the joint 610 is provided with a resilient cylindrical sleeve 638 which surrounds and engages the outside of the joint 610. This sleeve is made of a suitably resilient polymer material such as polyurethane or fiber reinforced polyurethane. It will be appreciated that other similar materials may also be suitably employed, with or without fiber reinforcement. The upper end of the sleeve 638 is attached to the outside of the housing 618 in the location designated at 640. The sleeve is preferably attached by means of compatible adhesives such as urethane adhesive, but it will be appreciated that other attachment means may be used as described below. The lower end of the sleeve 638 is also attached to the outside of the ring 628 in the location designated at 642 in a similar manner.

With the sleeve 638 fixedly attached to the housing and the ring, there is provided resilient resistance to rotation of the foot relative to the ankle. When the foot 616 is rotated about axis 626, the core 620 and ring 628, which are securely attached thereto, rotate with it. However, bearing means 622

allow the housing 618 and ankle 614 to remain unrotated. However, the torsional strength of the sleeve 638 resists this rotation, and will bring the foot back into its normal position when the rotational force is released. The magnitude of the resistance to rotation depends on the strength and thickness of the material which comprises the sleeve 638. A suitable sleeve comprised of polyurethane will preferably be in the range of 1/16" to 1/4" thick to provide adequate torsional resistance.

In alternative embodiments of the present invention, other means may be provided to attach the sleeve 638 to the housing 618 and ring 628 such as mechanical attachments. For example, the sleeve 638 may be attached by means of a plurality of screws 641 which are affixed circumferentially around the outside of the housing 618, as shown in FIG. 32. Alternatively, the sleeve 638 may be affixed around the outside of the housing 618 by means of a plurality of spring biased clips 643, also shown in FIG. 32, which firmly grip the top and bottom of the sleeve. It will be apparent to those skilled in the art that other attachment means may be provided which will satisfy the objects of the present invention. These various attachment configurations will allow selective reinstallation of various sleeves 638 which provide differing levels of resistance to rotation for different uses. For example, if a user desires to play basketball, a thicker or stiffer sleeve may be desired than for running or golf, or walking.

In the preferred embodiment of the present invention, the central area of the sleeve, designated at 644, comprises an annular bulge. This bulge provides additional material between the upper location of attachment 640 to the housing, and the lower location of attachment 642 to the ring. It will be appreciated that this bulge provides additional unfixed sleeve material between the locations of affixation, and allows reduced torsional resistance for a given thickness and material of the sleeve.

Turning to FIG. 33, there is shown a pictorial view of the prosthetic joint of the present invention connected to an energy-storing foot structure in its natural, un-deflected configuration. In this configuration, the forward axis 650 of the joint, intended to represent the forward walking direction, is aligned with the long axis of the foot 616, and the sleeve 638 is not stressed. FIG. 34, however, shows the foot 616 laterally deflected such that the long axis 652 of the foot is deflected from the forward axis 650 of the joint by some angle 654. This rotational deflection creates a torsional stress in the sleeve 638, deforming the bulge 644 into some deformed bulge 644a. In this situation the torsional elasticity of the sleeve 638 resists the rotation, and tends to rotate the foot back into its natural undeflected configuration. It is this function of the present invention which provides its primary utility. For example, a user of this device would have greater mobility when playing basketball, for example, by being able to plant the foot firmly on the ground and

still rotate the leg somewhat, as can be done by ordinary human legs.

FIG. 35 shows a pictorial view of an alternative embodiment of the sleeve 638 of the present invention. In this embodiment the resilient sleeve 638 is provided with a plurality of vertically oriented slots 660 located about the middle, bulged region 644 of the sleeve. Alternatively, as shown in FIG. 37, the sleeve may be provided with slots 660a that are oriented in a slanted configuration relative to the vertical axis 626. Alternatively again, as shown in FIG. 38, the sleeve may be provided with slots 660b that are curved relative to the vertical axis 626. It will be apparent that the slots 660b may be curved in any desired configuration such as having a single curvature as shown in FIG. 38, or having double curvature as shown with the curved slits 661b in FIG. 40, described below, or any other desired configuration. As noted above with regard to the bulge 644, the slots 660, 660a, or 660b likewise reduce the torsional resistance of the sleeve for a given thickness and choice of material, the magnitude of the reduction depending in part on the configuration of the slots. Normally these slots will not extend into the upper and lower regions of affixation, 640 and 642, so as not to compromise the strength of affixation of the sleeve to the housing 618 and the ring 628.

As an alternative to the slots of FIGs. 35, 37, and 38, a resilient sleeve 638b having vertical slits 661 in its side may be provided as shown in FIG. 36.

Alternatively, as shown in FIG. 39, the sleeve may be provided with slits 661a that are oriented in a slanted configuration relative to the vertical axis 626, or as shown in FIG. 38, the slits 661b may be curved relative to the vertical axis 626. As noted above with respect to the slots, the curved slits 661b may also be curved in any desired configuration such as having double curvature as shown in FIG. 40, or having single curvature like the slots shown in FIG. 38, or any other desired configuration. The slits may penetrate through the full thickness of the sleeve 638b, or may be partial depth, depending on the desired torsional stiffness of the sleeve.

It is to be understood that the described embodiments of the invention are illustrative only, and that modifications thereof may occur to those skilled in the art. Accordingly, this invention is not to be regarded as limited to the embodiments disclosed, but is to be limited only as defined by the appended claims herein.

CLAIMS

What is claimed is:

1. A prosthetic foot comprising:

at least two resilient forefoot members disposed in a lateral, side-by-side relationship and having base ends coupled near an attachment location and extending forward to toe ends at a toe location, the at least two forefoot members having a range of motion with multiple stages of advancement including at least a normal range and an extreme range and having a resistance response to an applied force; and

at least one resilient forefoot reinforcement member having a base section coupled to at least one of the at least two forefoot members and extending to a free section proximal to the toe location and spaced above the at least two resilient forefoot members, the free section being disposed within the extreme range of motion of the at least two forefoot members and freely movable with respect to the at least two forefoot members, the forefoot reinforcement member having a range of motion within the extreme range of motion of the at least two forefoot members, such that the forefoot reinforcement member influences the range of motion and resistance response of the at least two forefoot members.

2. The prosthetic foot of claim 1, wherein the at least one forefoot reinforcement member comprises

a first forefoot reinforcement member having a base section coupled to a first forefoot member and extending to a free section operable within the range of motion of the first forefoot member, and

a second forefoot reinforcement member having a base section coupled to a second forefoot member and extending to a free section operable within the range of motion of the second forefoot member.

3. The prosthetic foot of claim 1, wherein the at least one forefoot reinforcement member comprises

a primary forefoot reinforcement member having a base section coupled to at least one of the at least two forefoot members and extending to a free section operable within the range of motion of the at least two forefoot members, the primary forefoot reinforcement member having a range of motion within a primary extreme range of motion of the at least two forefoot members, and

a secondary forefoot reinforcement member having a base section coupled to at least one of the at least two forefoot members and extending to a free section operable within the range of motion of the at least two forefoot members, the secondary forefoot reinforcement member having a range of motion within a secondary extreme range of motion of the at least two forefoot members and within the range of motion of the primary forefoot reinforcement member.

4. The prosthetic foot of claim 1, further comprising

at least one resilient heel member having a base end coupled to at least one of the at least two resilient forefoot members and extending rearward to a heel end at a heel location, the at least one heel member having a range of motion including a normal

range and an extreme range and having a resistance response to an applied force.

5. The prosthetic foot of claim 4, further comprising

at least one heel resilient reinforcement member having a base section coupled to at least one of the at least two forefoot members and extending to a free section operable within the range of motion of the at least one heel member, the free section being freely movable with respect to the at least one heel member, such that the heel reinforcement member influences the range of motion and resistance response of the at least one heel member.

6. The prosthetic foot of claim 4, further comprising:

at least one heel reinforcement member having a base section coupled to at least one of the at least one forefoot reinforcement member and extending rearward to a free section operable within the range of motion of the at least one heel member.

7. The prosthetic foot of claim 4, wherein the at least one heel reinforcement member comprises

a first heel reinforcement member having a base section coupled to a first heel member and extending to a free section operable within the range of motion of the first heel member, and

a second heel reinforcement member having a base section coupled to a second heel member and extending to a free section operable within the range of motion of the second heel member.

8. The prosthetic foot of claim 4, wherein the at least one heel reinforcement member comprises

a primary heel reinforcement member having a base section coupled to at least one of the at least two forefoot members and extending to a free section operable within the range of motion of the at least one heel member, the primary heel reinforcement member having a range of motion within a primary extreme range of motion of the at least one heel member, and

a secondary heel reinforcement member having a base section coupled to at least one of the at least two forefoot members and extending to a free section operable within the range of motion of the at least one heel member, the secondary heel reinforcement member having a range of motion within a secondary extreme range of motion of the at least one heel member and within the range of motion of the primary heel reinforcement member.

9. The prosthetic foot of claim 1, further comprising

a limiting means coupled between the free section of the at least one forefoot reinforcement member and the at least two forefoot members such that the limiting means prevents the at least two forefoot members from abruptly returning to an unstressed position when an applied force is removed.

10. The prosthetic foot of claim 9, wherein the limiting means comprises a strap.

11. The prosthetic foot of claim 1, further comprising

a contact means disposed between the free section of the at least one forefoot reinforcement member and the at least two forefoot members such that the at least two forefoot members engage the at least one forefoot reinforcement member when the at least two forefoot members move from the normal range of movement to the extreme range of movement.

12. A prosthetic foot comprising:

a resilient forefoot member having a base end coupled proximal an attachment location and extending forward to a toe end at a toe location, the forefoot member defining an arch section between the base end and the toe end, and having a range of motion with multiple stages of advancement including at least a normal range and an extreme range and having a resistance response to an applied force; and

a forefoot reinforcement member having a base section coupled to the forefoot member at the arch section and extending to a free end at a location between the arch section and the attachment section and spaced from the forefoot member, the free end being disposed within the extreme range of motion of the forefoot member and having a range of motion within the extreme range of motion of the forefoot member, such that the forefoot reinforcement member influences the range of motion and resistance response of the forefoot member.

13. The prosthetic foot of claim 12, further comprising:

a flexible restraint coupled to and between the free end of the forefoot reinforcement member and

the forefoot member, the restraint being flexible in a direction towards the forefoot reinforcement member to allow the forefoot member to move towards the forefoot reinforcement member, but substantially non-flexible in a direction away from the forefoot reinforcement member to couple the forefoot member to the forefoot reinforcement member in movement away from the forefoot reinforcement member.

14. The prosthetic foot of claim 12, further comprising:

a resilient heel member having a base end coupled to the resilient forefoot member and extending rearward to a heel end at a heel location, the heel member having a range of motion including a normal range and an extreme range and having a resistance response to an applied force.

15. The prosthetic foot of claim 12, wherein a flexible cushion is disposed between the free end of the forefoot reinforcement member and the forefoot member.

16. The prosthetic foot of claim 12, wherein an air bag containing air is disposed between the free end of the forefoot reinforcement member and the forefoot member.

17. The prosthetic foot of claim 12, further comprising:

a secondary forefoot reinforcement member having a base section coupled to the forefoot member at the arch section and extending to a free end proximal the toe location and spaced above the toe end of the forefoot member, the free end of the secondary

forefoot reinforcement member being disposed within the extreme range of motion of the forefoot member and having a range of motion within the extreme range of motion of the forefoot member, such that the secondary forefoot reinforcement member influences the range of motion and resistance response of the forefoot member.

18. The prosthetic foot of claim 12, further comprising:

a heel reinforcement member having a base section coupled to the forefoot member at the arch section and extending under the forefoot member to a free end proximal the attachment location, the free section being disposed within the extreme range of motion of the forefoot member and moveable with respect to the forefoot member, the heel reinforcement member having a range of motion within the extreme range of motion of the forefoot member, such that the heel reinforcement member influences the range of motion and resistance response of the forefoot member and the heel member.

19. The prosthetic foot of claim 12, further comprising:

a flexible and resilient wedge member disposed between the forefoot member and the forefoot reinforcement member at a location proximal to the attachment.

20. A prosthetic foot comprising:

a resilient forefoot member having a base end coupled proximal an attachment location and extending forward to a toe end at a toe location, the forefoot member defining an arch section between the

base and toe ends, and having a range of motion with multiple stages of advancement including at least a normal range and an extreme range and having a resistance response to an applied force;

a resilient heel member having a base end coupled to the resilient forefoot member and extending rearward to a heel end at a heel location, the heel member having a range of motion including a normal range and an extreme range and having a resistance response to an applied force; and

a heel reinforcement member having a base section coupled to the forefoot member at the arch section and extending to a free end proximal to a location between the arch section and the attachment location, the free section being disposed within the extreme range of motion of the forefoot member and moveable with respect to the forefoot member, the heel reinforcement member having a range of motion within the extreme range of motion of the forefoot member, such that the heel reinforcement member influences the range of motion and resistance response of the forefoot member and the heel member.

21. The prosthetic foot of claim 20, wherein the heel reinforcement member forms an arcuate section extending near the heel location and within the extreme range of motion of the heel member.

22. The prosthetic foot of claim 20, further comprising:

a flexible restraint coupled to and between the free end of the heel reinforcement member and the forefoot member, the restraint being flexible in a

direction towards the heel reinforcement member to allow the forefoot member to move towards the heel reinforcement member, but substantially non-flexible in a direction away from the heel reinforcement member to couple the forefoot member to the heel reinforcement member in movement away from the heel reinforcement member.

23. The prosthetic foot of claim 20, wherein a flexible cushion is disposed between the free end of the heel reinforcement member and the forefoot member.

24. The prosthetic foot of claim 20, wherein an air bag containing air is disposed between the free end of the heel reinforcement member and the forefoot member.

25. The prosthetic foot of claim 20, further comprising:

a forefoot reinforcement member having a base section coupled to the forefoot member at the arch section and extending above the forefoot member to a free end proximal the attachment location and spaced from the forefoot member, the free end being disposed within the extreme range of motion of the forefoot member and having a range of motion within the extreme range of motion of the forefoot member, such that the forefoot reinforcement member influences the range of motion and resistance response of the forefoot member.

26. The prosthetic foot of claim 20, further comprising:

a secondary forefoot reinforcement member having a base section coupled to the forefoot member

at the arch section and extending to a free end proximal the toe location and spaced above the toe end of the forefoot member, the free end of the secondary forefoot reinforcement member being disposed within the extreme range of motion of the forefoot member and having a range of motion within the extreme range of motion of the forefoot member, such that the secondary forefoot reinforcement member influences the range of motion and resistance response of the forefoot member.

27. The prosthetic foot of claim 20, further comprising:

a flexible and resilient wedge member disposed between the forefoot member and the heel member at a location proximal to the attachment.

28. A prosthetic foot simulating toe and related axial foot rotation, comprising:

a fixture member;

a first member coupled to the fixture member, the first member having a forefoot member and a heel member, the forefoot member forming a resilient arc extending between the fixture member and a toe position, the heel member extending between the forefoot member and a heel position; and

a second member independently moveable with respect to the first member and coupled to the fixture member adjacent the first member, the second member having a forefoot member and a heel member, the forefoot member forming a resilient arc extending between the fixture member and a toe position, the heel member forming a resilient arc extending between

the forefoot member and a heel position for simulating the toe and axial rotation of a foot.

29. The prosthetic foot of claim 28, wherein the heel member is attached to the forefoot member by wrapping the members with a resin impregnated fiber.

30. The prosthetic foot of claim 28, further comprising:

a mating means for coupling the forefoot member with the heel member and preventing the forefoot member from sliding or twisting with respect to the heel member.

31. The prosthetic foot of claim 30, wherein the mating means comprises a rib and groove connection between the forefoot member and the heel member.

32. The prosthetic foot of claim 31, wherein the rib and groove connection is formed in the forefoot member and heel member in a longitudinal orientation.

33. The prosthetic foot of claim 31, wherein the rib and groove connection is formed in the forefoot member and the heel member in a lateral orientation.

34. The prosthetic foot of claim 28, further comprising: a resilient member coupled between the forefoot member and the heel member.

35. The prosthetic foot of claim 28, further comprising:

a secondary heel member coupled to the forefoot member between the forefoot member and the heel member, the secondary heel member forming a resilient arc extending between the forefoot member and a heel position.

36. The prosthetic foot of claim 28, further comprising:

an angle adjustment means for adjusting the angle of the forefoot member with respect to the fixture member and the ground.

37. A prosthetic foot simulating toe and related axial foot rotation, comprising:

a fixture member;

an elongated resilient forefoot member coupled to the fixture member, the forefoot member forming a resilient arc extending between the fixture member and a toe position;

a resilient heel member coupled to the forefoot member, the heel member forming a resilient arc extending between the forefoot member and a heel position; and

a slit formed in the forefoot member, the slit extending from an open end at the toe position to at least the heel member, the slit forming a first protrusion and a second protrusion in the forefoot member for simulating the toe and axial rotation of a foot.

38. The prosthetic foot of claim 37, wherein the heel member is attached to the forefoot member by wrapping the members with a resin impregnated fiber.

39. The prosthetic foot of claim 37, further comprising:

a mating means for coupling the forefoot member with the heel member and preventing the forefoot member from sliding or twisting with respect to the heel member.

40. The prosthetic foot of claim 39, wherein the mating means comprises a rib and groove connection between the forefoot member and heel member.

41. The prosthetic foot of claim 40, wherein the rib and groove connection is formed in the forefoot member and heel member in a longitudinal orientation.

42. The prosthetic foot of claim 40, wherein the rib and groove connection is formed in the forefoot member and the heel member in a lateral orientation.

43. The prosthetic foot of claim 37, further comprising:

a resilient member coupled between the forefoot member and the heel member.

44. The prosthetic foot of claim 37, further comprising:

a secondary heel member attached to the forefoot member between the forefoot member and the heel member, the secondary heel member forming a resilient arc extending between the forefoot member and a heel position.

45. The prosthetic foot of claim 37, further comprising:

an angle adjustment means for adjusting the angle of the forefoot member with respect to the fixture member and the ground.

46. A prosthetic foot, comprising:

a fixture member;

an elongated resilient forefoot member coupled to the fixture member, the forefoot member forming a resilient arc extending between the fixture member and a toe position;

a resilient heel member attached to the forefoot member, the heel member forming a resilient arc extending between the forefoot member and a heel position; and

a mating means for coupling the forefoot member with the heel member and preventing the forefoot member from sliding or twisting with respect to the heel member.

47. The prosthetic foot of claim 46, wherein the heel member is attached to the forefoot member by wrapping the members with a resin impregnated fiber.

48. The prosthetic foot of claim 46, wherein the mating means comprises a rib and groove connection between the forefoot member and heel member.

49. The prosthetic foot of claim 48, wherein the rib and groove connection is formed in the forefoot member and heel member in a longitudinal orientation.

50. The prosthetic foot of claim 48, wherein the rib and groove connection is formed in the forefoot member and the heel member in a lateral orientation.

51. The prosthetic foot of claim 46, further comprising:

a resilient member coupled between the forefoot member and the heel member.

52. The prosthetic foot of claim 46, further comprising:

a slit formed in the forefoot member, the slit extending from an open end at the toe position to at least the heel member, the slit forming a first protrusion and a second protrusion in the forefoot member.

53. A device for joining a prosthetic appendage to a prosthetic limb, comprising:

rotatable bearing means having a proximal portion and a distal portion, said proximal portion being configured for fixation to an end of a prosthetic limb, and said distal portion being affixed to said appendage;

a generally cylindrical sleeve of resilient material having a top portion, a bottom portion, a central portion, an inside surface, and an outside surface, said sleeve oriented so as to surround the bearing means with its long axis colinear to an axis of rotation of the bearing means, the inside surface of the top portion of the sleeve being affixed to the proximal portion of the rotatable bearing means, the inside surface of the bottom portion of the sleeve being affixed to the distal portion of the rotatable bearing means, such that when the proximal and distal portions of the bearing means are rotated relative to each other, such rotation is resiliently resisted by torsional flexure of the central portion of the sleeve.

54. The apparatus as described in claim 53 wherein the central portion of said sleeve further comprises a bulge around the circumference of the sleeve and directed away from the rotatable bearing means, such that the magnitude of torsional resistance provided by the central portion of the sleeve is modified.

55. The apparatus as described in claim 54 further comprising stress relief means formed in the central portion of the sleeve, said stress relief means extending at least partially between the outside surface and the inside surface of the sleeve, and configured to reduce the resistance of the sleeve to torsional flexure.

56. The apparatus as described in claim 55 wherein the stress relief means is selected from the group comprising a plurality of slots and a plurality of slits formed in the sleeve.

57. The apparatus as described in claim 56 wherein the stress relief means are oriented parallel to the central axis of the cylindrical sleeve.

58. The apparatus as described in claim 57 wherein the stress relief means extends from the outside surface to the inside surface of the sleeve.

59. The apparatus as described in claim 53 wherein the cylindrical sleeve is formed of materials selected from the group consisting of polyethylene, polypropylene, polyurethane, polyvinyl, urethane, rubber, and fiber reinforced composites of the foregoing polymers.

60. The apparatus as described in claim 59 wherein the material is in the range of 1/16 in. to 1/4 in. thick.

61. The apparatus as described in claim 59 wherein the ratio of the length of the sleeve measured along its central axis to the thickness of the material is in the range of 4:1 to 16:1.

62. The apparatus as described in claim 53 wherein the sleeve is affixed to the rotatable bearing means by means of an adhesive.

63. The apparatus as described in claim 53 wherein the sleeve is affixed to the rotatable bearing means by mechanical connection means.

64. The apparatus as described in claim 63 wherein the mechanical connection means is selectively releasable by a user of the apparatus such that a user may remove and replace sleeves at will, so as to allow selective installation of sleeves of varying resistance.

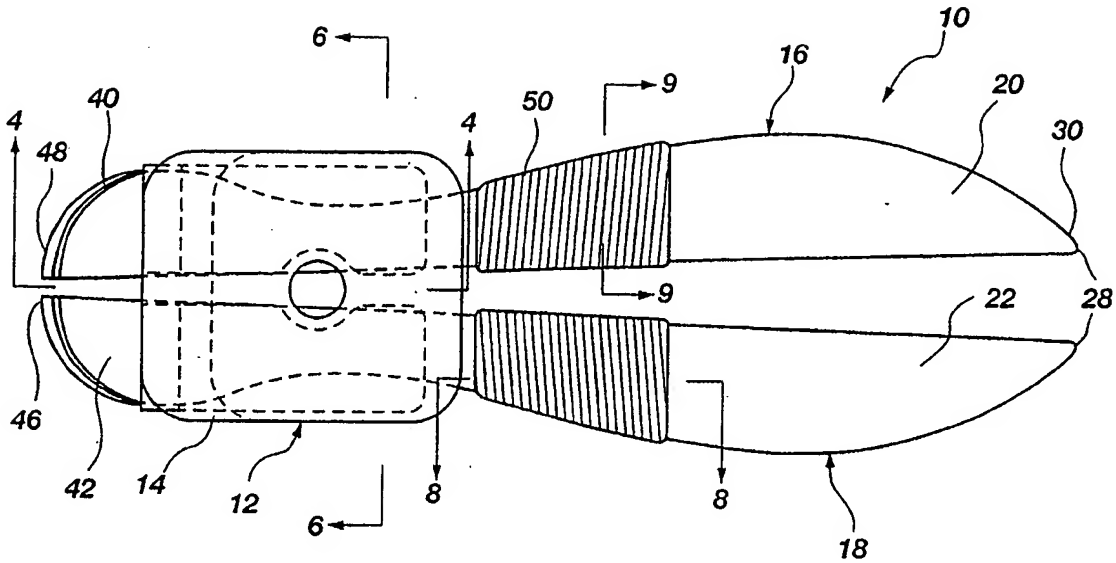
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Fig. 1

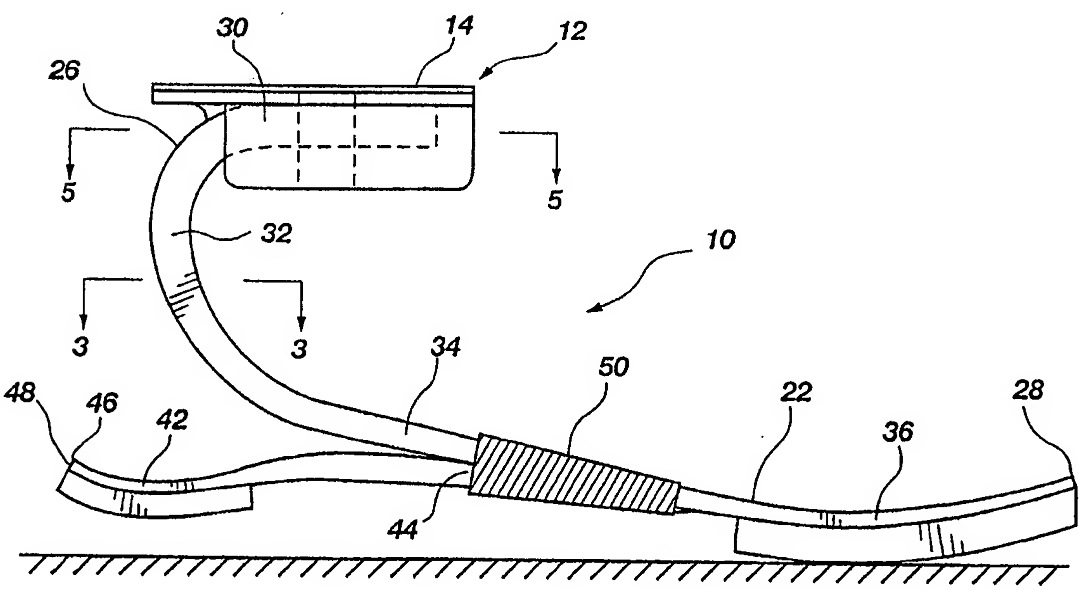
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Fig. 2

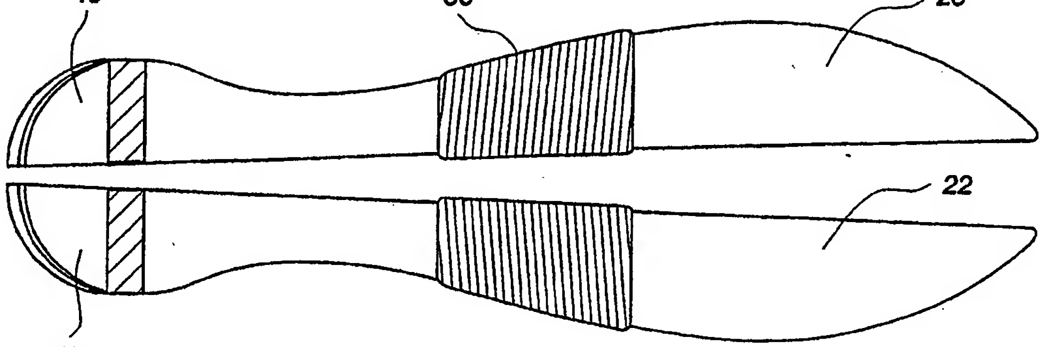

Fig. 3

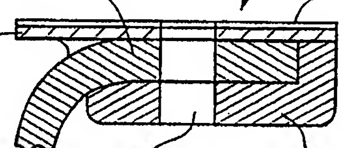

Fig. 4

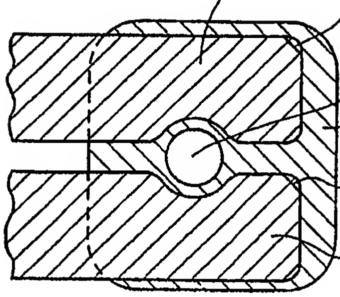

Fig. 5

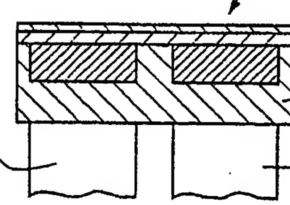

Fig. 6

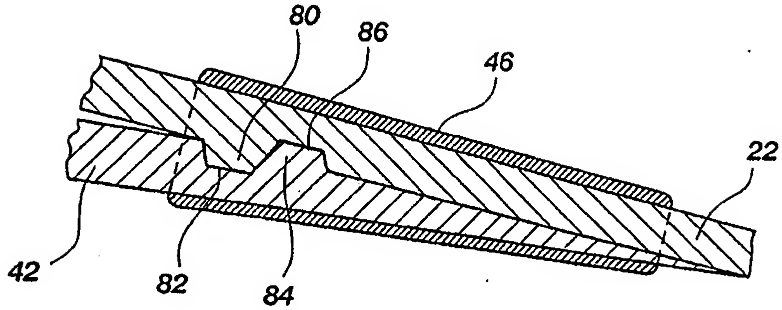

Fig. 8

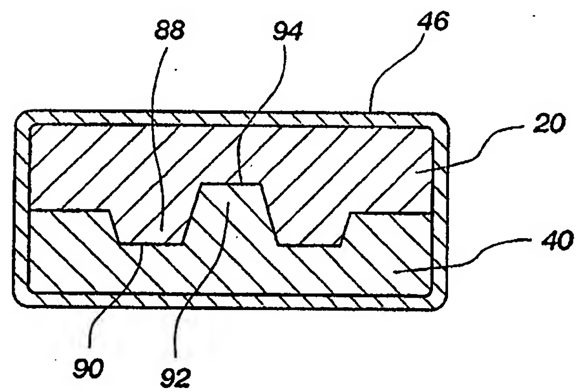

Fig. 9

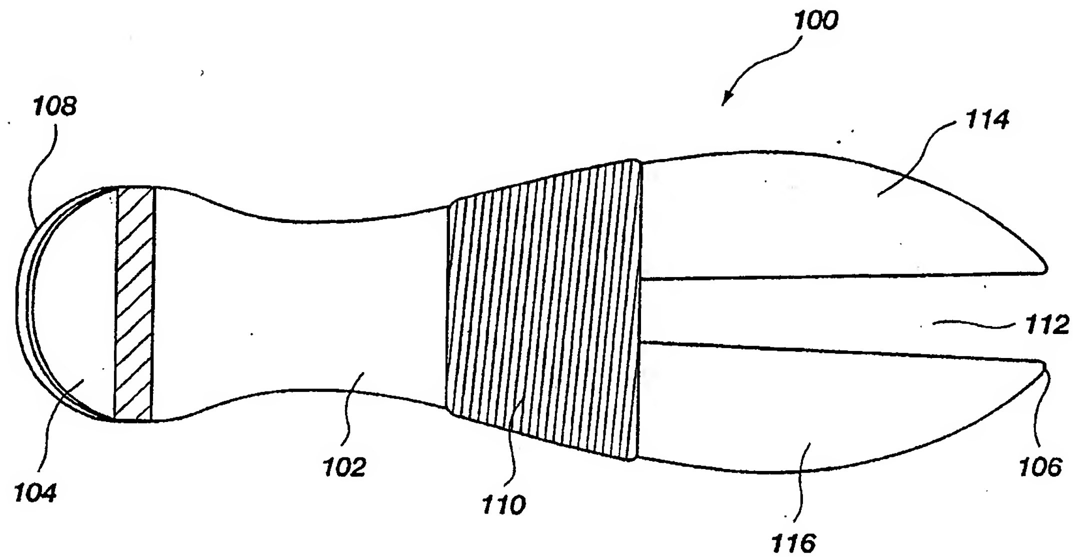

Fig. 10

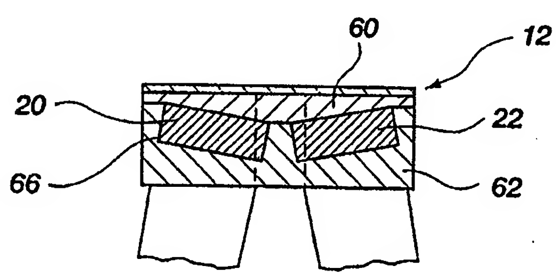

Fig. 7

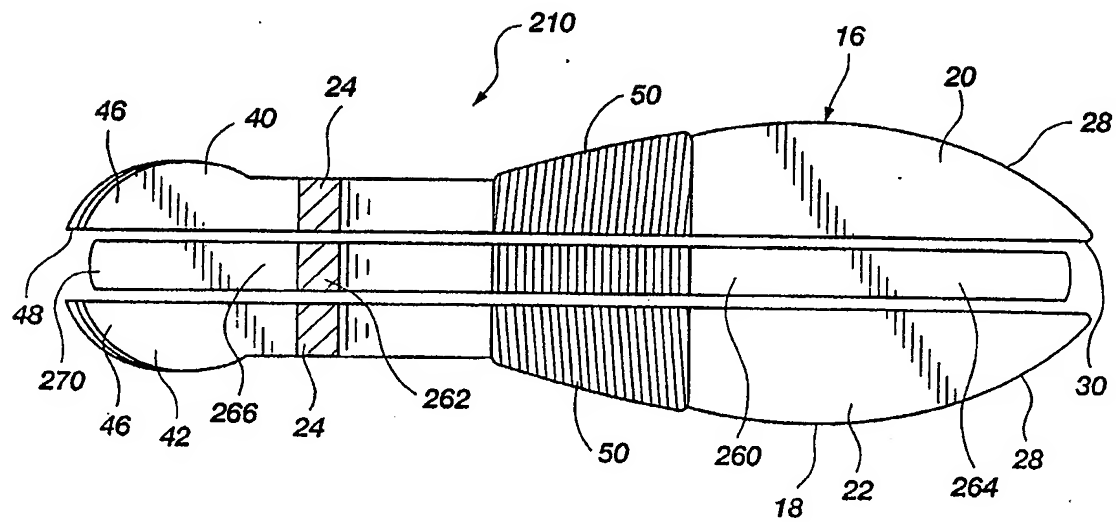
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Fig. 11

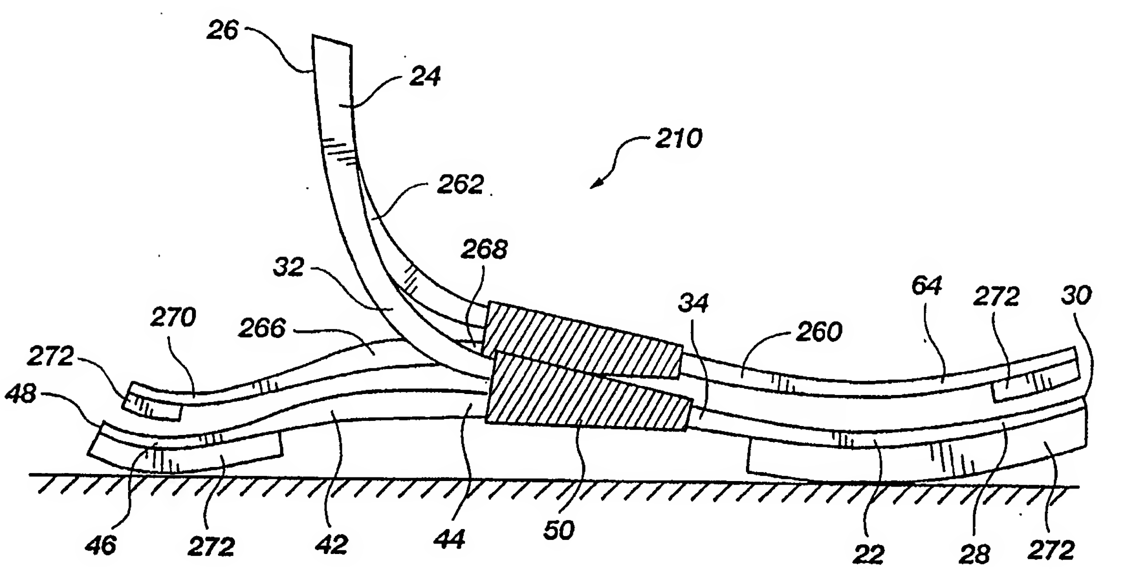
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Fig. 12

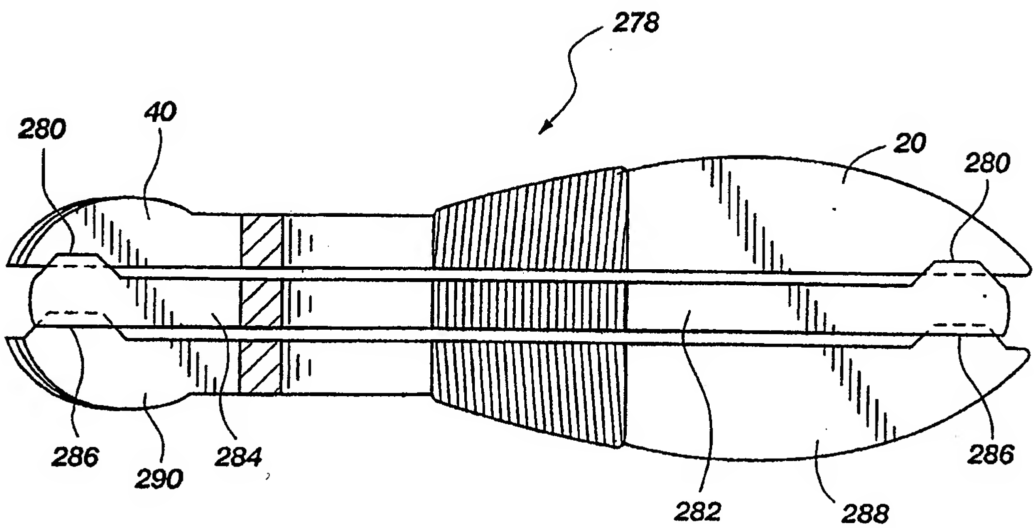
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Fig. 13

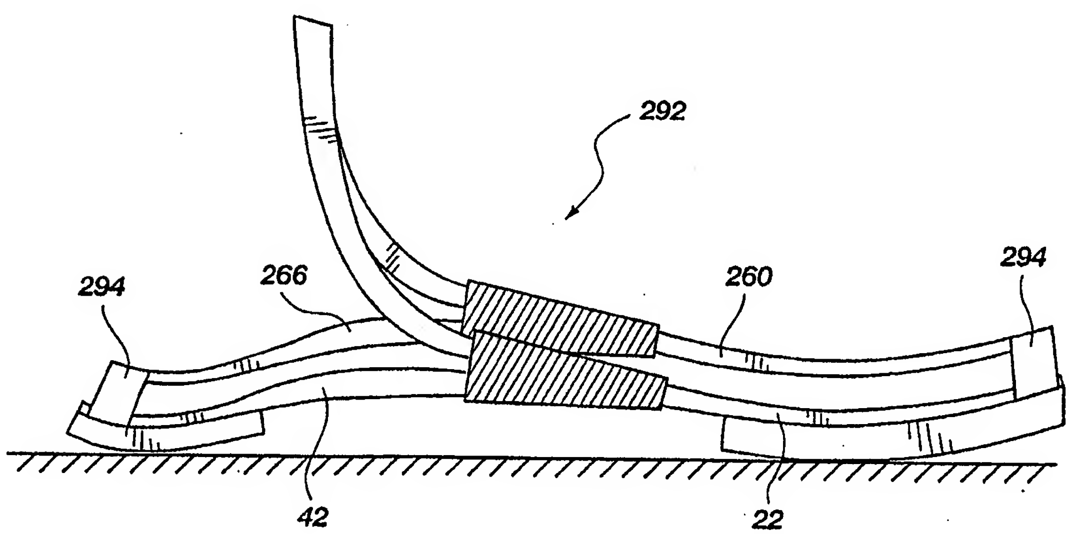
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Fig. 14

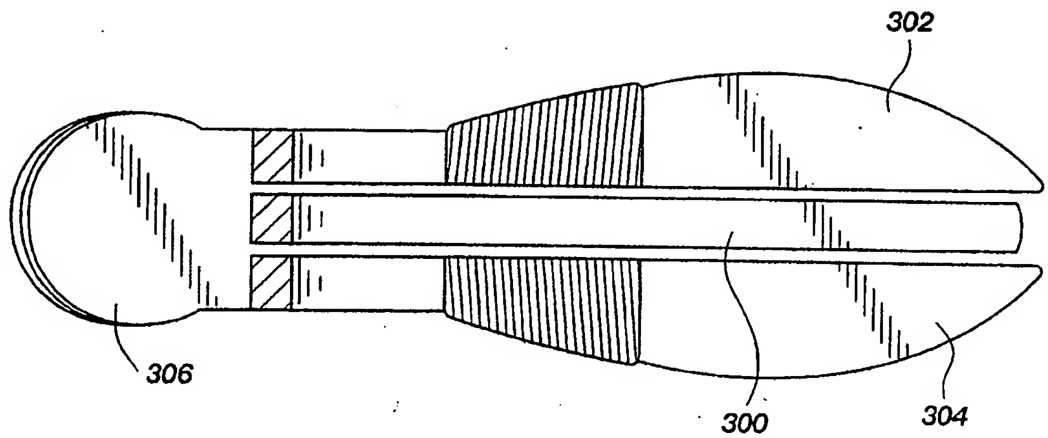


Fig. 15

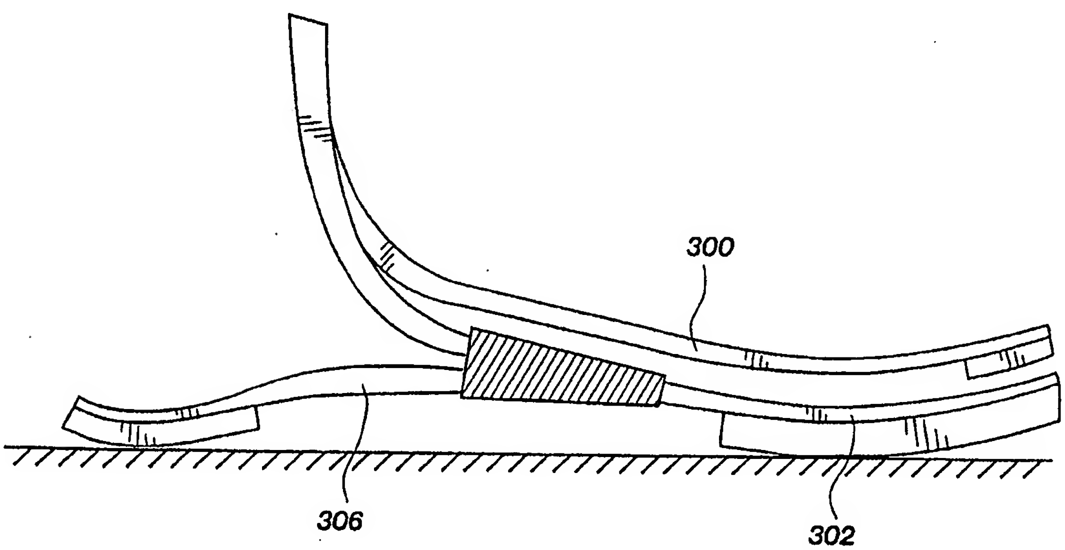


Fig. 16

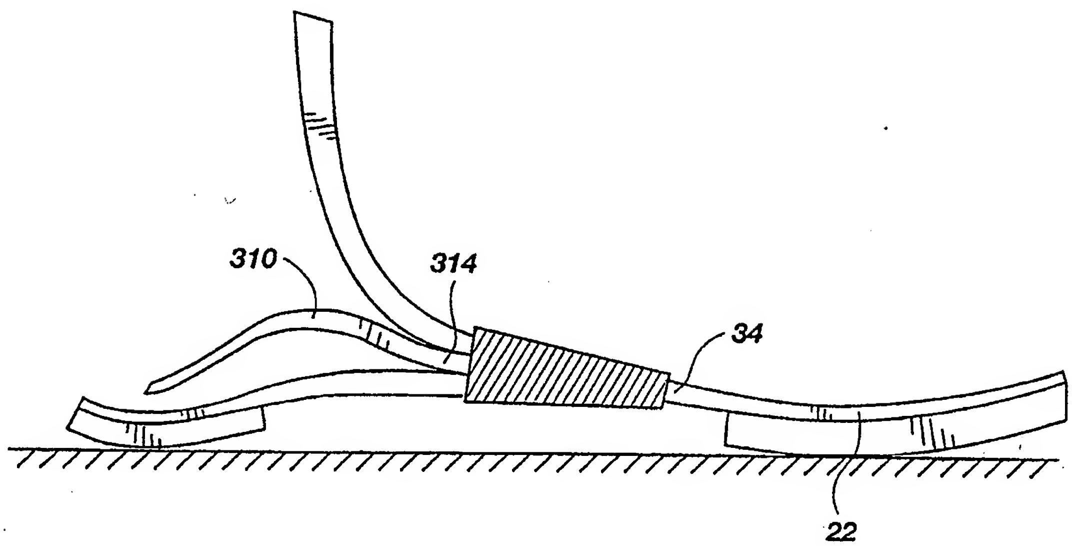
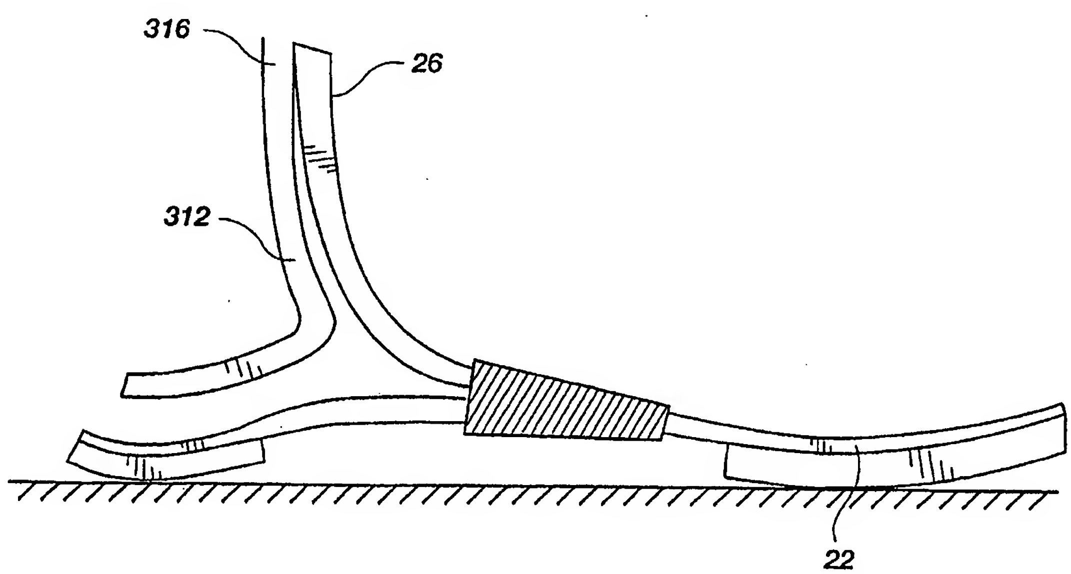


Fig. 17



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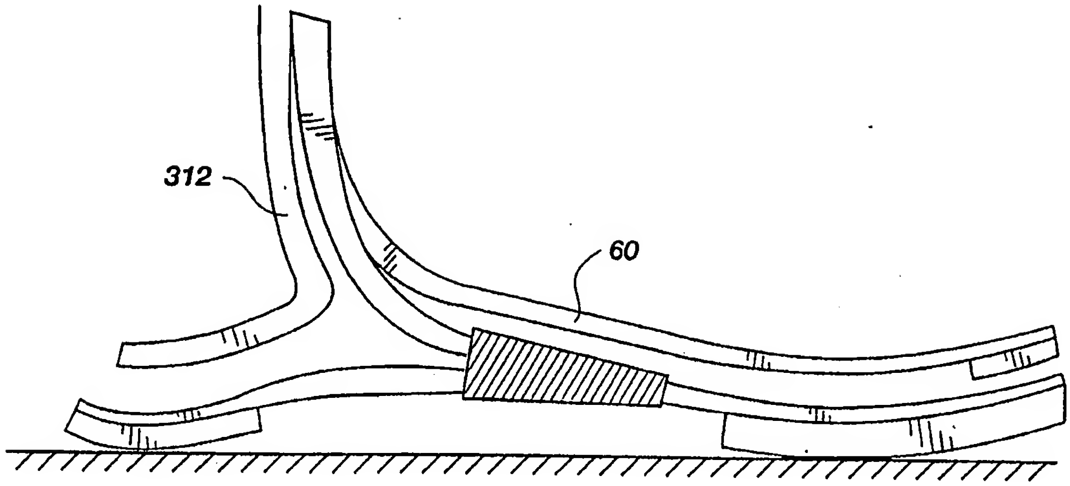


Fig. 19

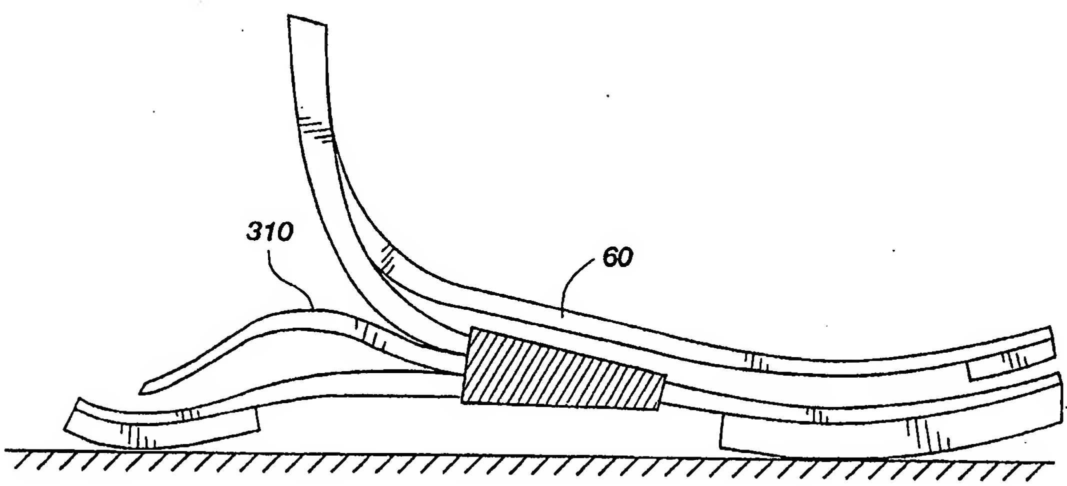
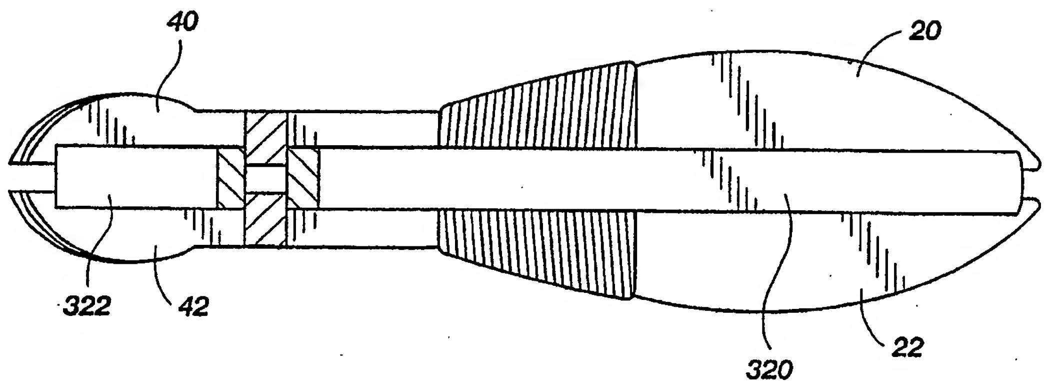


Fig. 20



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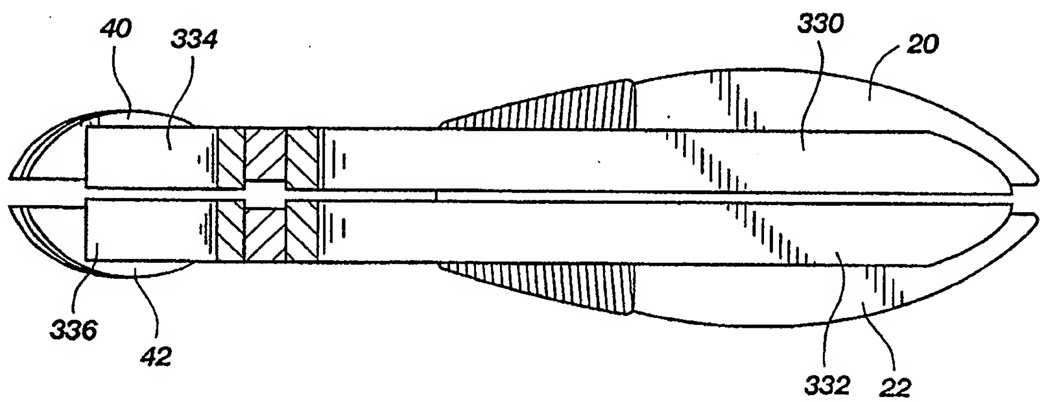

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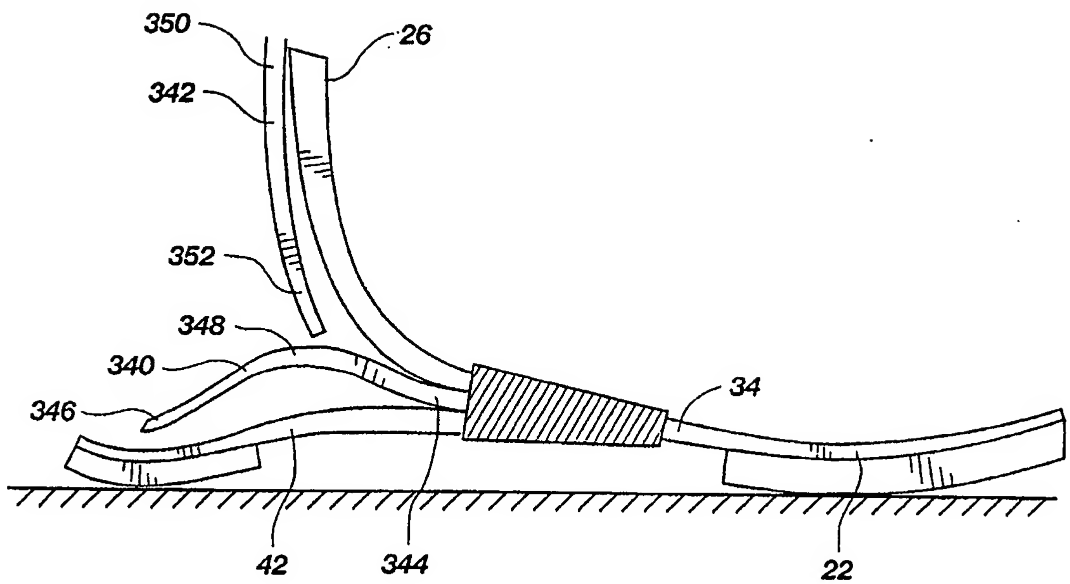

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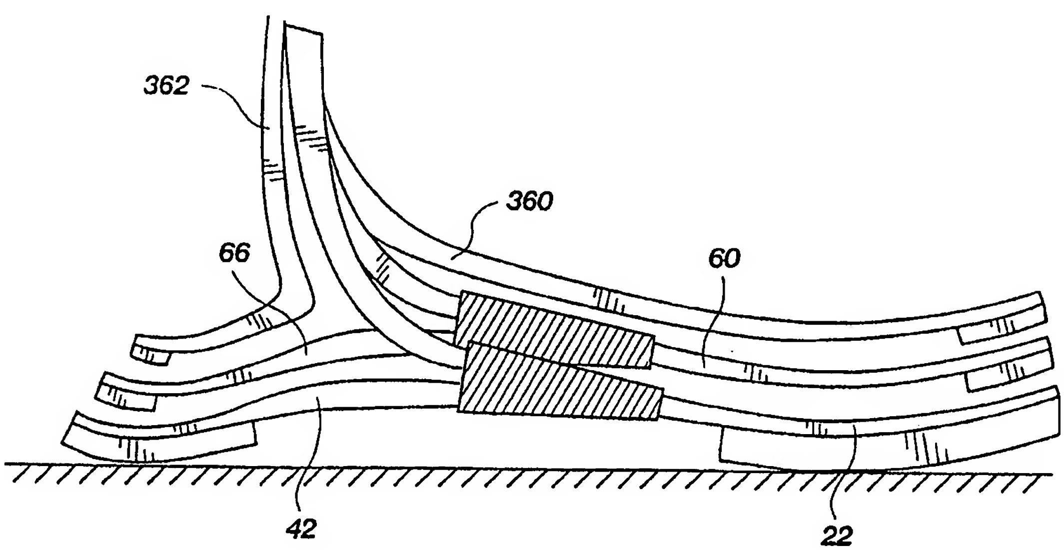

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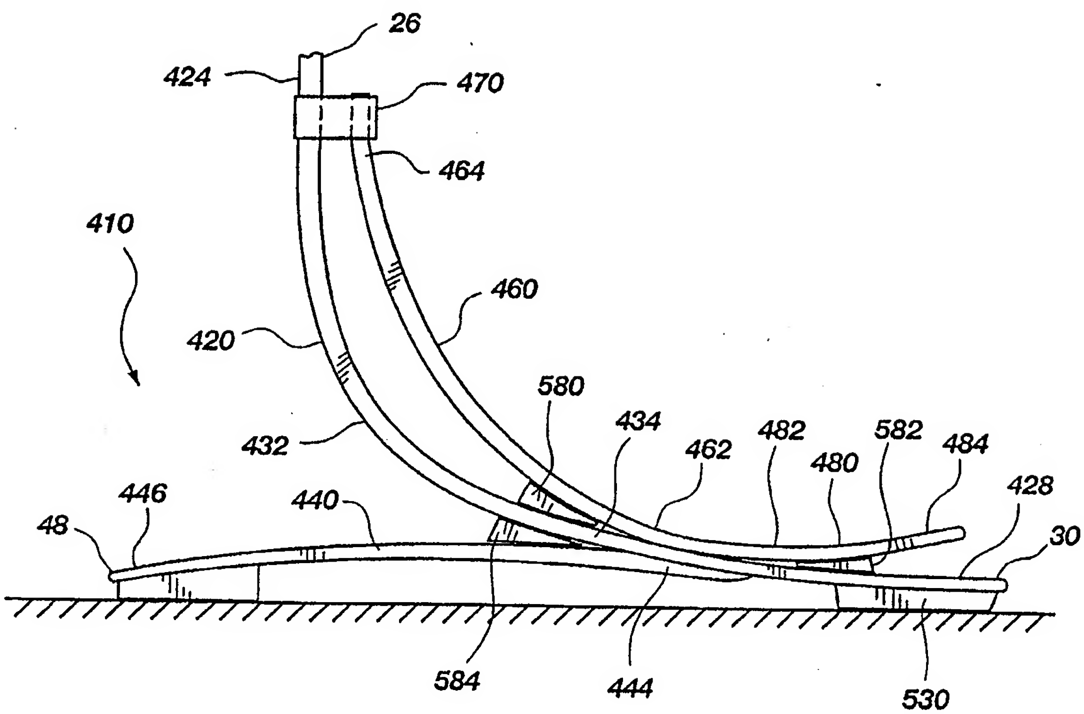
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Fig. 25

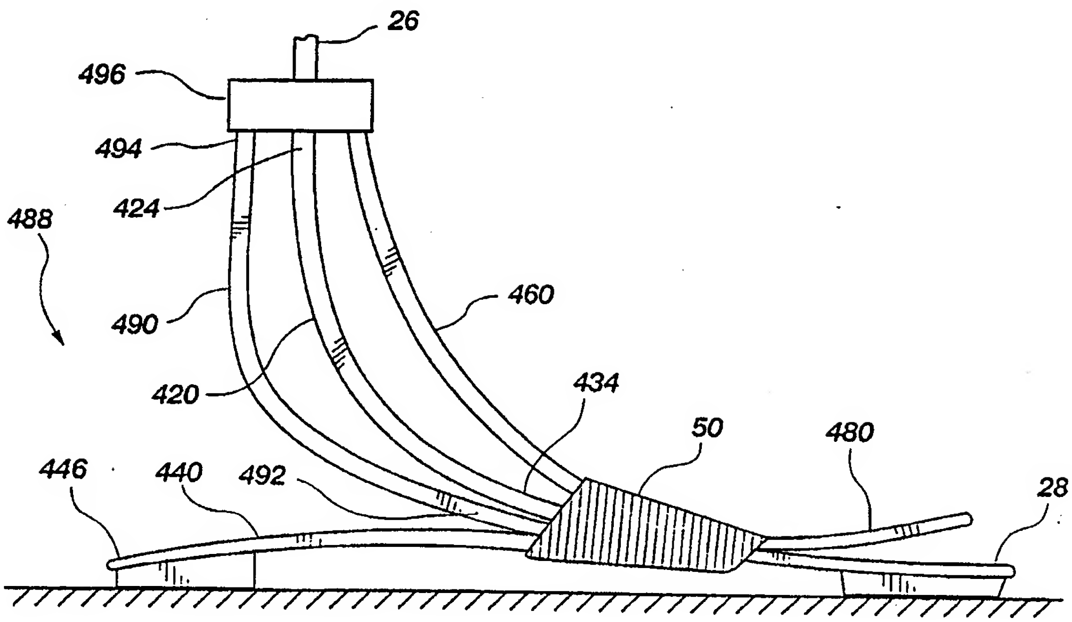
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Fig. 26

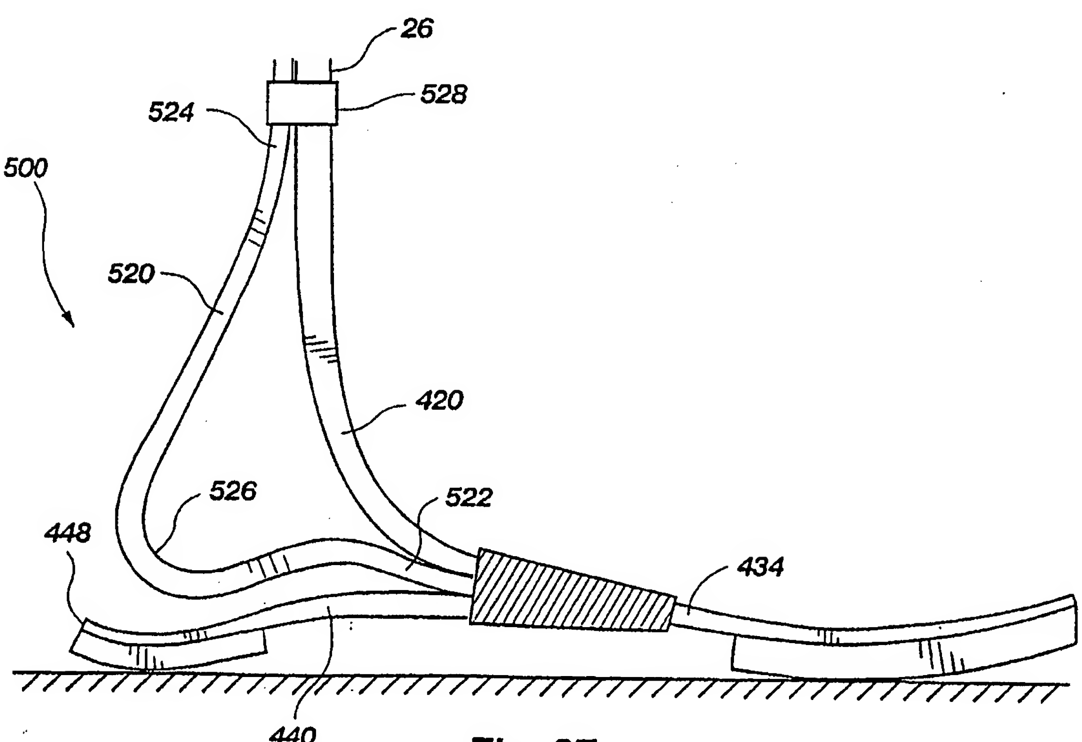
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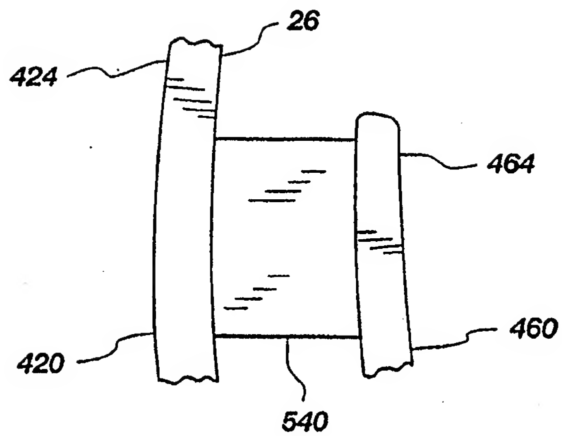
Fig. 27



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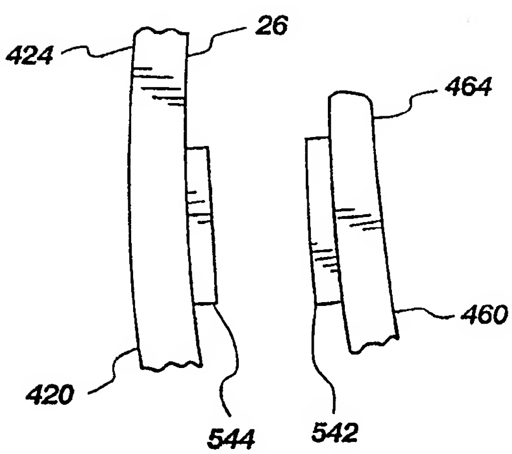

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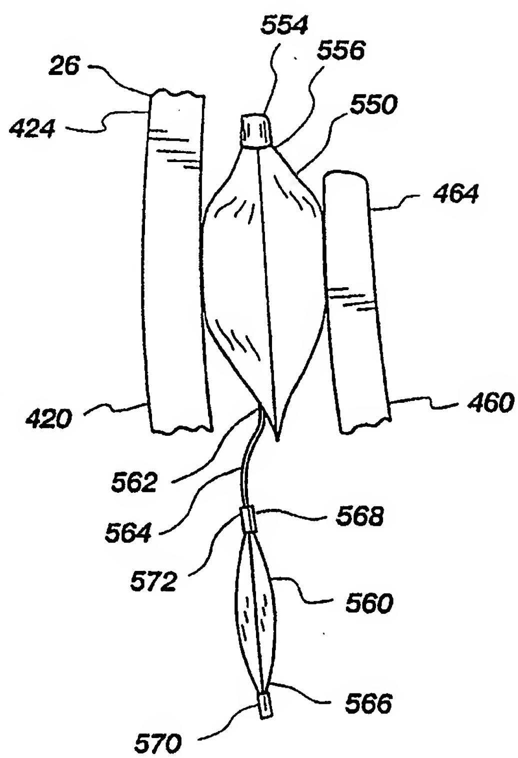

Fig. 30

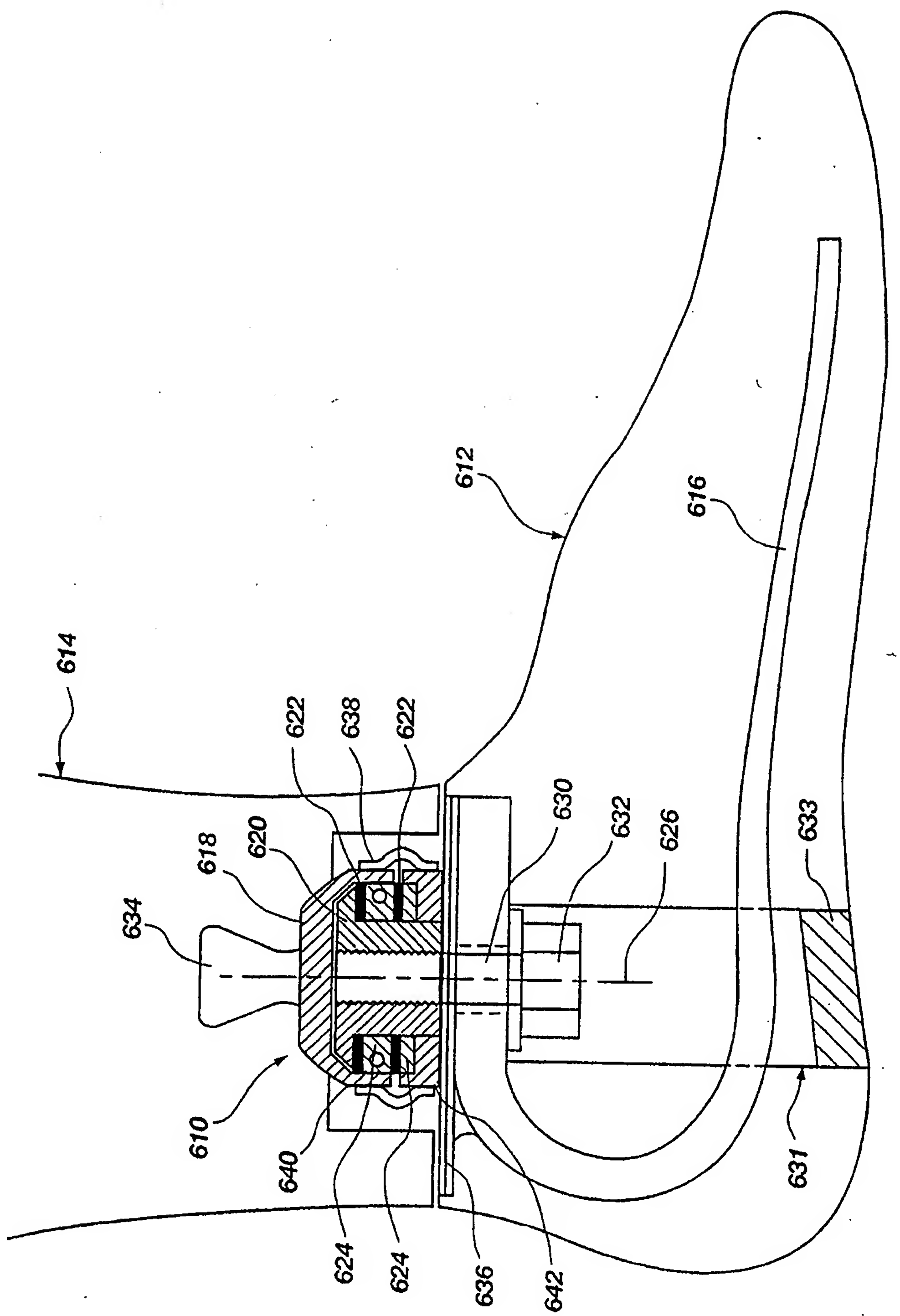
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Fig. 31

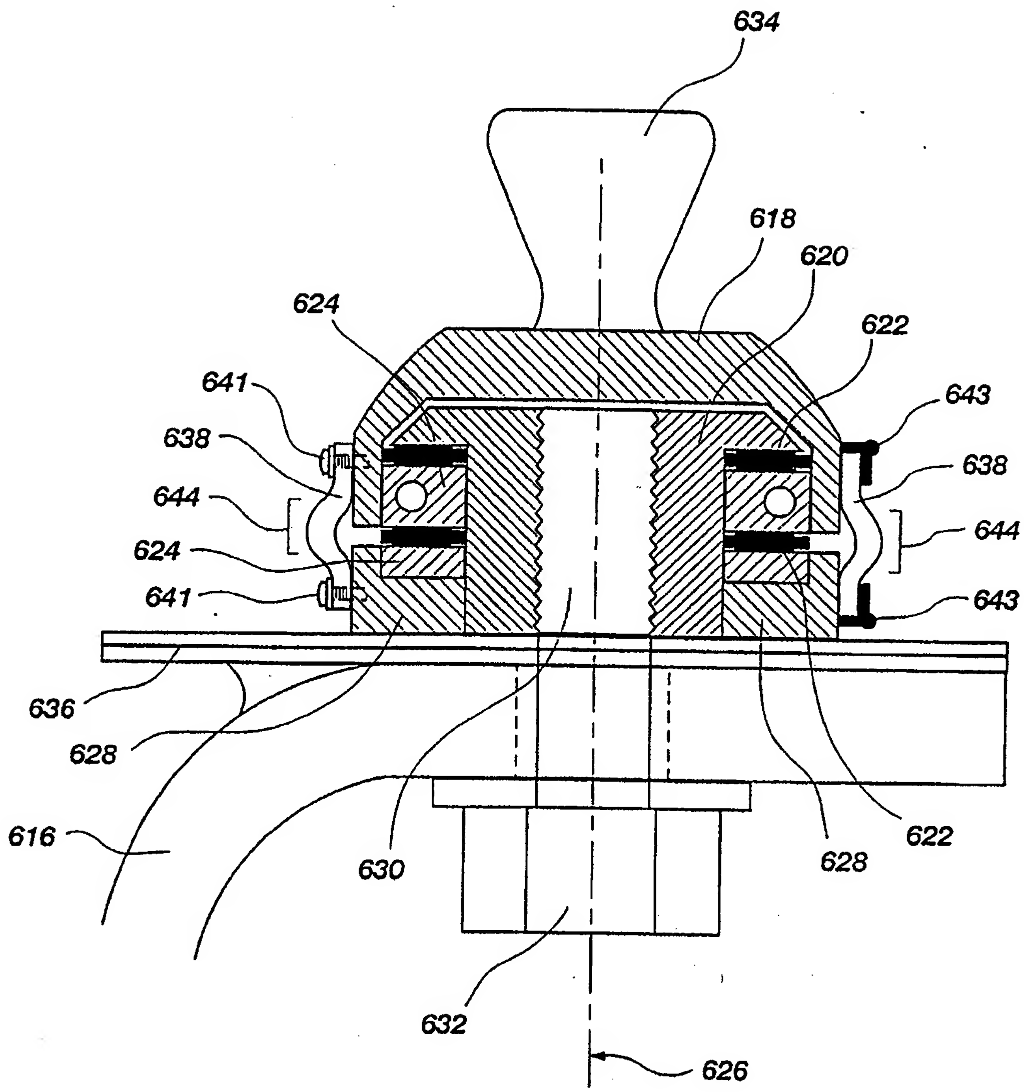
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Fig. 32

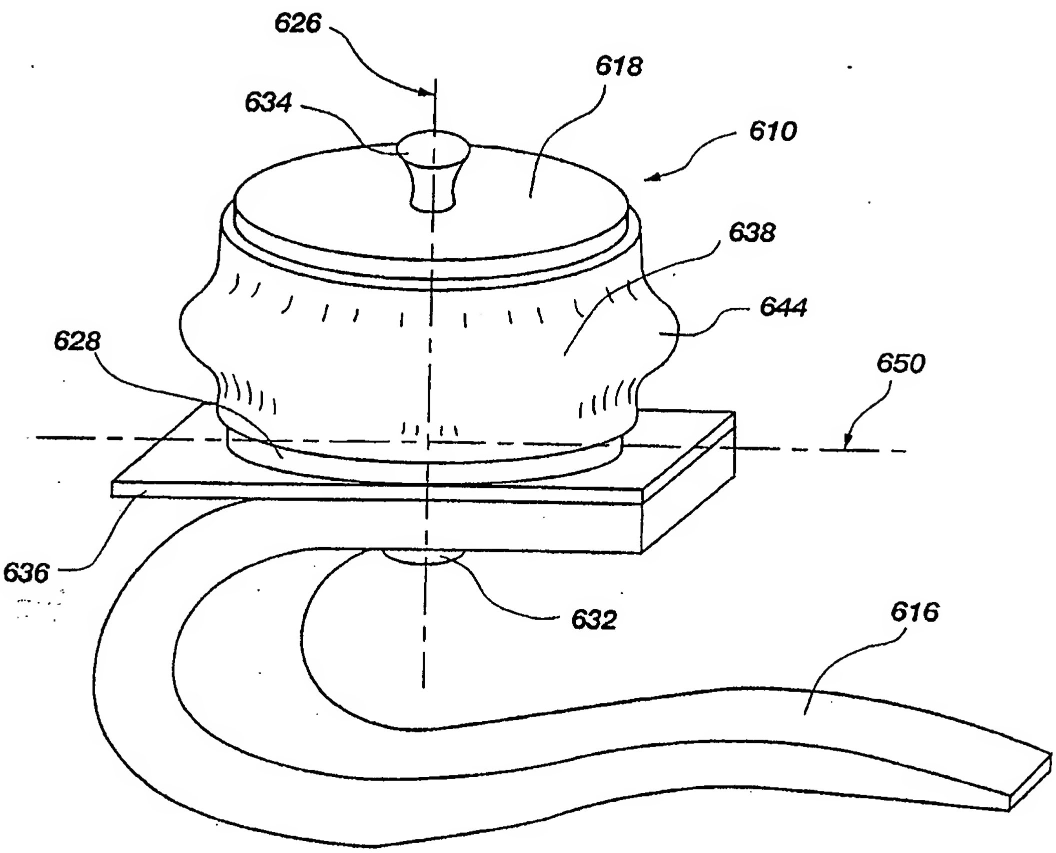

Fig. 33

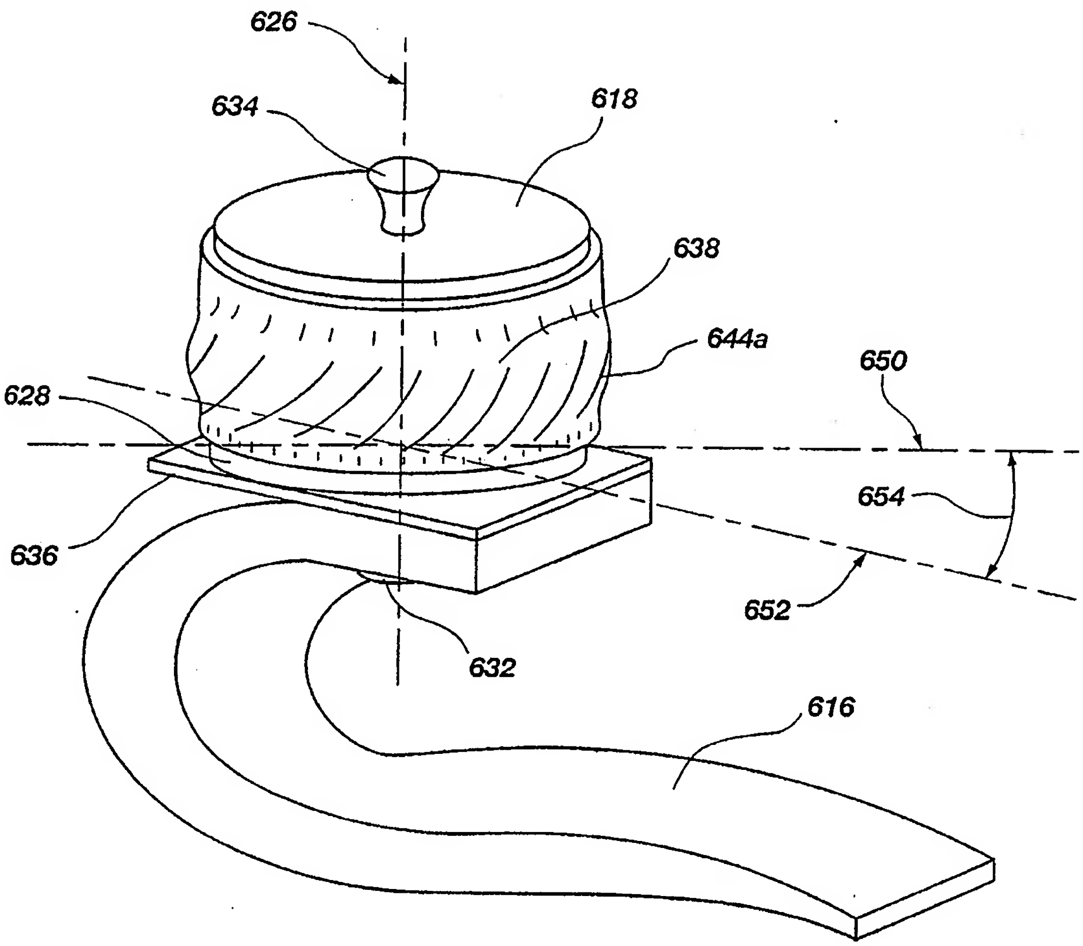

Fig. 34

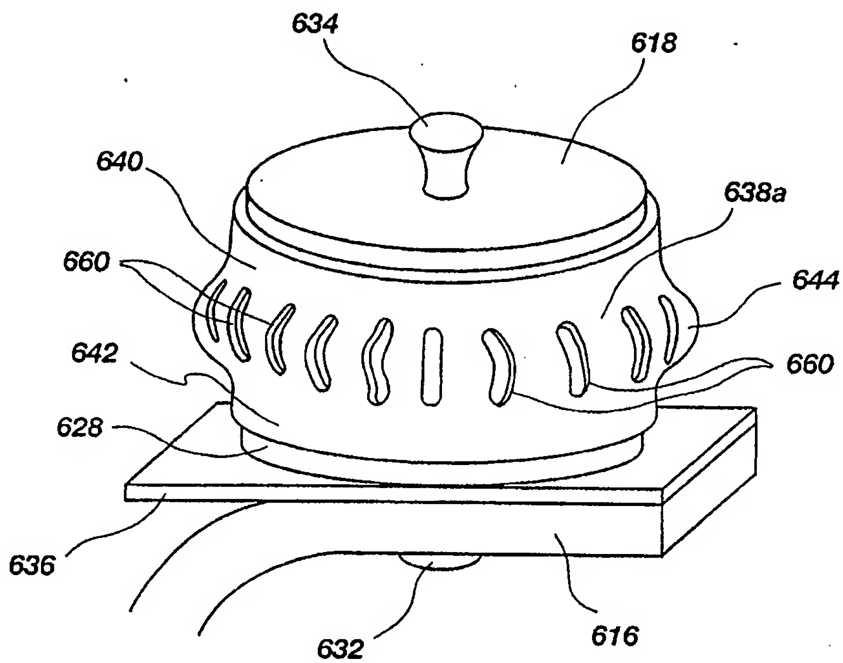

Fig. 35

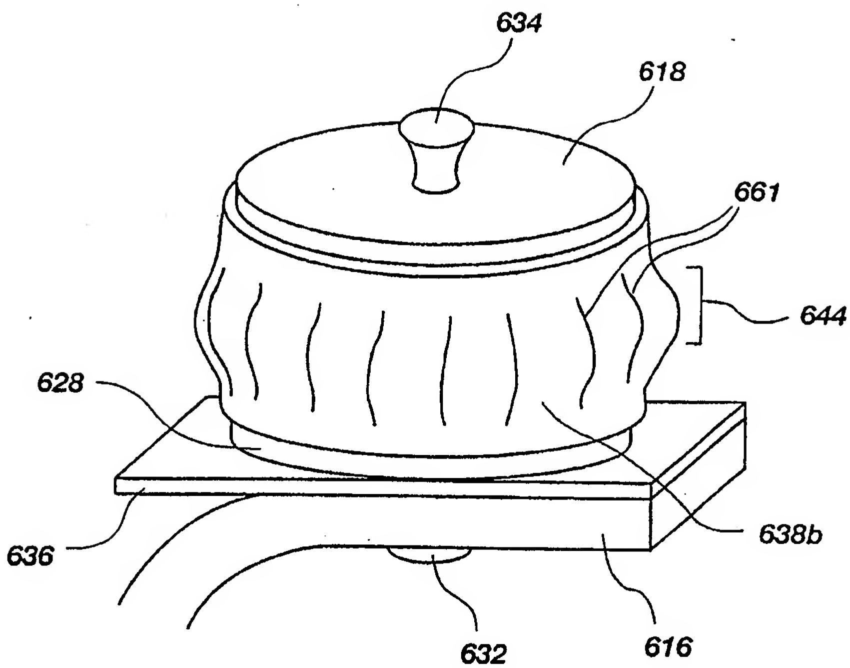

Fig. 36

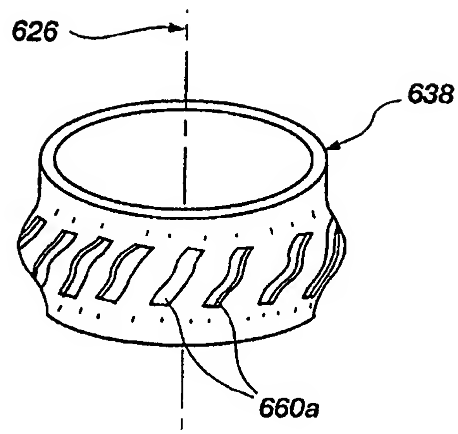

Fig. 37

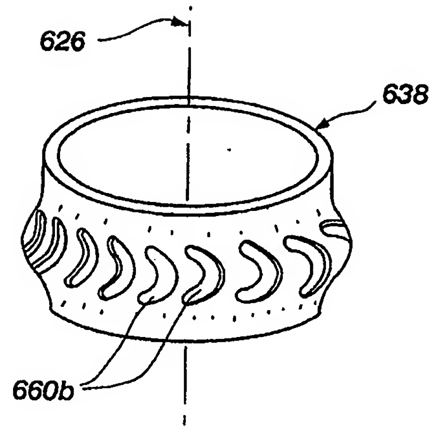

Fig. 38

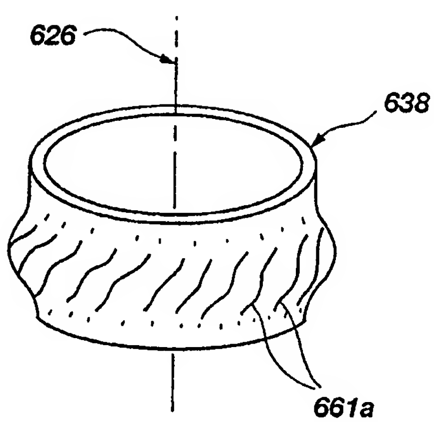

Fig. 39

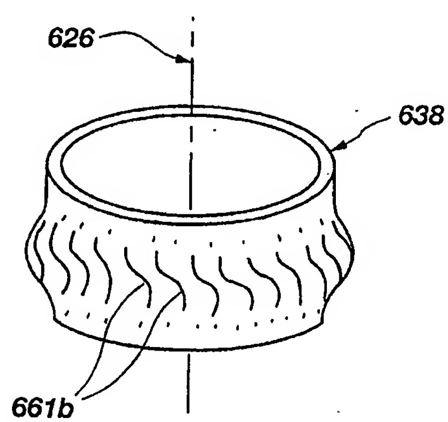

Fig. 40

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/18638

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A61F 2/66
US CL :623/52.55
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 623/52.55

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,387,246 A (PHILLIPS) 07 February 1995, entire document, especially Figs. 11-14.	12-16, 19 --- 17, 18, 20-27
X --- Y	US 5,290,319 A (PHILLIPS) 01 March 1994, Figs. 1-3.	46 --- 47, 51
X --- Y	US 5,181,933 A (PHILLIPS) 26 January 1993, figures, col. 2 lines 3-20.	28, 30, 34, 37, 39, 43, 46, 51, 52 --- 29, 36, 38, 45, 47

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

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Date of the actual completion of the international search	Date of mailing of the international search report
10 DECEMBER 1999	02 FEB 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer DAVE WILLSE
Facsimile No. (703) 305-3230	Telephone No. (703) 308-2903

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/18638

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 5,653,767 A (ALLEN et al.) 05 August 1997, figures, col. 5 lines 20-52, col. 7 lines 17-30, and col. 8 lines 3-5.	28, 30, 31, 33-37, 39, 40, 42-46, 48, 50-52 ---------------- 32, 41, 49
X --- Y	US 4,938,775 A (MORGAN) 03 July 1990, Fig. 4, col. 5 line 54 et seq., and col. 6 lines 44-47.	53-56, 59-61, 63, 64 ---------------- 62